

# Measurements of B Rare Decays at the Tevatron

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for the CDF and D $\emptyset$  Collaborations

Les Rencontres de Moriond – QCD and Hadronic Interactions  
La Thuile, March 17-24, 2007

## Topics:

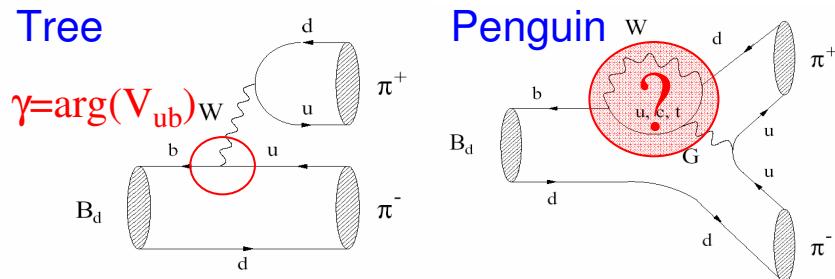
- **$B \rightarrow h^+h^-$  (charmless) recent results**
- **$B \rightarrow \mu\mu$  search status**
- **$B \rightarrow \mu\mu h$  updates**

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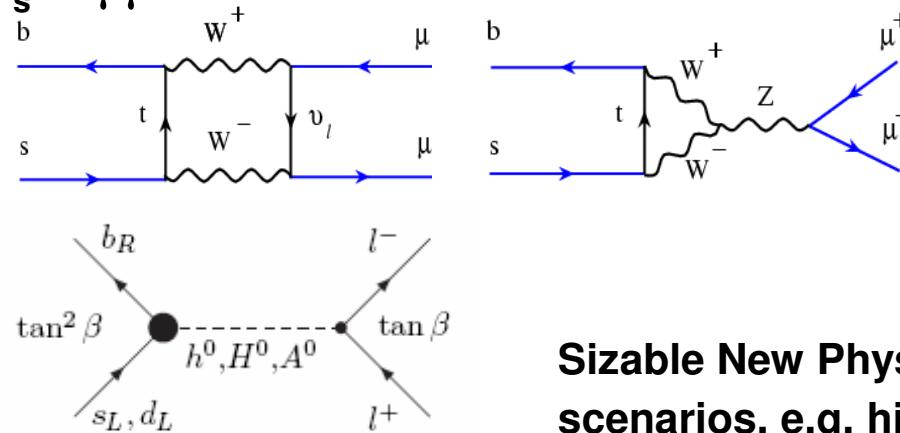
## Why Rare ( $\text{BR} \lesssim 10^{-6}$ ) or lower) B Decays are so interesting ?

### 1) Charmless $B \rightarrow h^+ h^-$



- a useful tool for probing CKM
- sensitive to the New Physics contributions in the Penguin diagrams
- sensitive to New Physics effects via anomalies in  $A_{CP}$

### 2) $B_s \rightarrow \mu\mu$

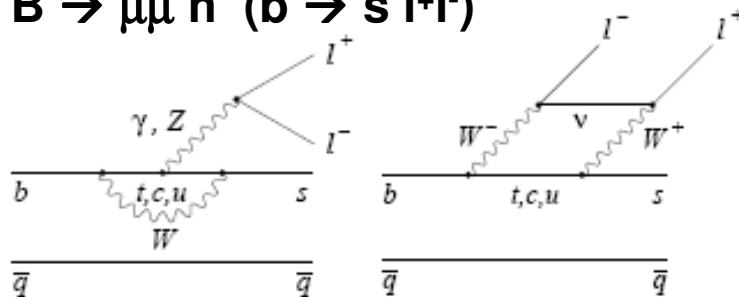


$$BR(B_s \rightarrow \mu^+ \mu^-)^{CMFV} < 7.42 \times 10^{-9}$$

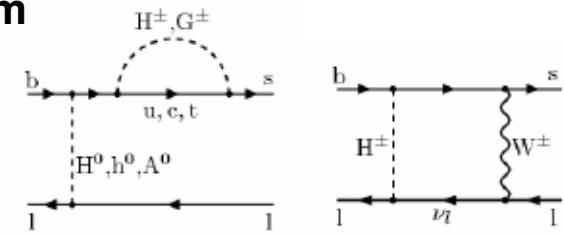
(T.Hurth, hep-ph/0612231v1)

Sizable New Physics enhancement predicted in non MFV scenarios, e.g. high  $\tan\beta$  SUSY ( $\mathcal{B}^{\text{SUSY}}(B \rightarrow \mu\mu) \propto (\tan\beta)^6$ )

### 3) $B \rightarrow \mu\mu h^-$ ( $b \rightarrow s l^+ l^-$ )



Additional information on the flavor dynamics of FCNC decays from the s-quark and di-lepton system FB asymmetries



# Heavy Flavor physics at the Tevatron

$\sigma(bb)$  at Tevatron is  $O(10^5)$  larger than production in  $e^+e^-$  colliders at  $Y(4s)$  or  $Z^0$  energy scale

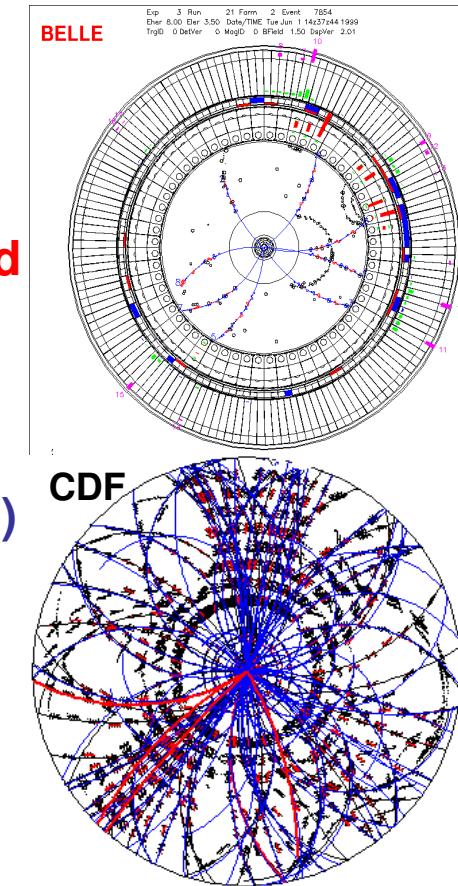
- -- all b-hadrons ( $B^+$ ,  $B^0$ ,  $B_s$ ,  $B_c$ ,  $\Lambda_b$ ,  $\Sigma_b$ ,.....) are produced
- physics program complementary to the B-Factories

Fine, but...

- The total inelastic x-section is a factor  $10^3$  larger than  $\sigma(\bar{b}\bar{b})$
- The BRs of rare b-hadron decays are  $O(10^{-6})$  or lower

therefore.....

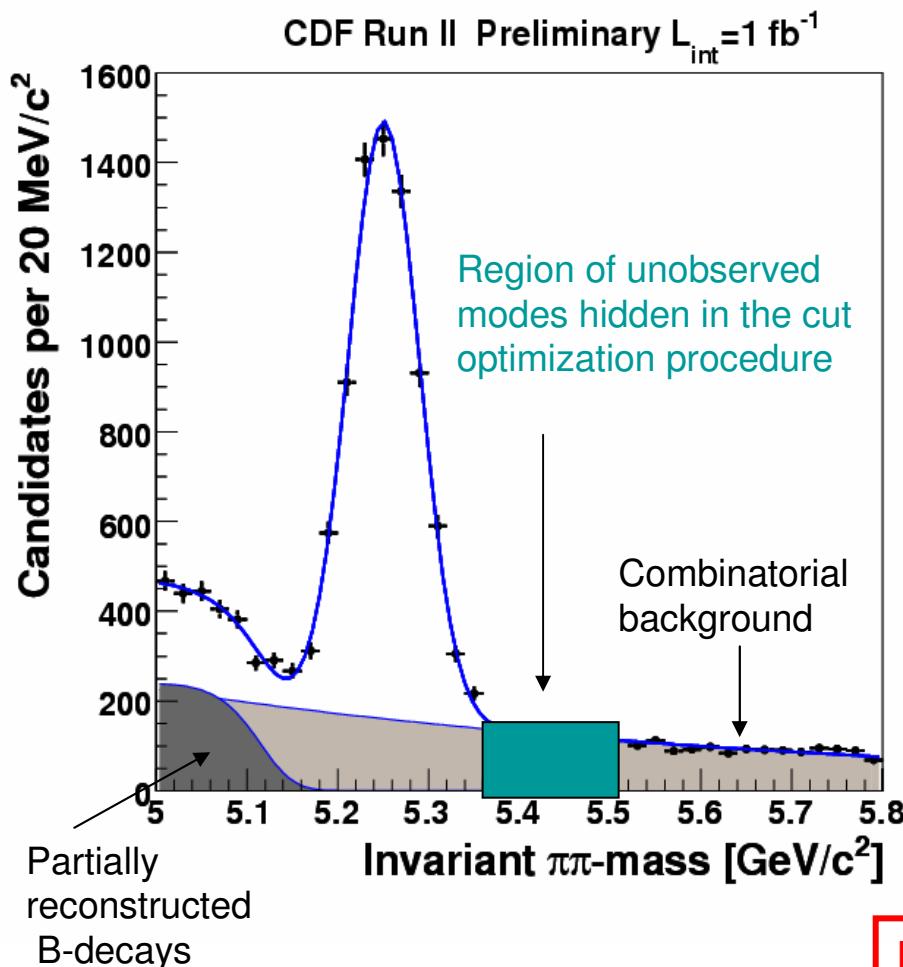
Interesting events must be extracted from a high track multiplicity environment.....



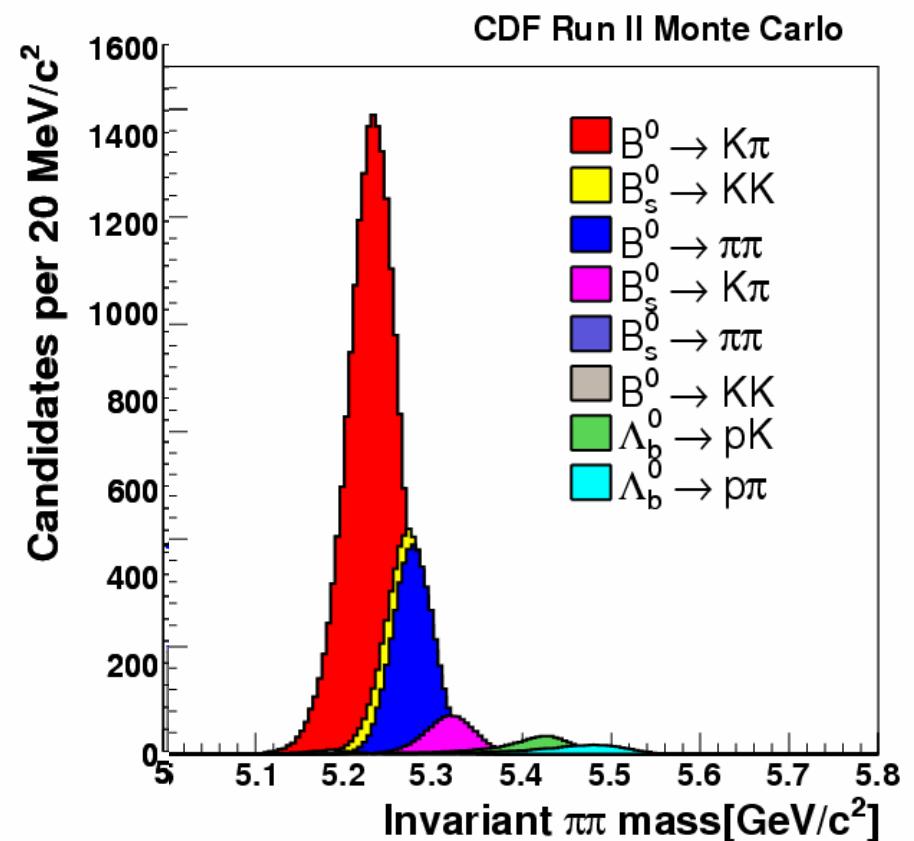
Detectors need to have:

- Very good tracking and vertex resolution
- Wide acceptance and good ID for electrons and muons
- Highly selective trigger

**B → h<sup>+</sup> h'**



**B → h<sup>+</sup> h':  $\pi\pi$  invariant mass**



Individual modes overlap in a single peak !

Signal composition is determined with a **Likelihood Fit**, combining information from kinematics (mass and momenta) and particle identification ( $dE/dx$ ).

## B → h<sup>+</sup> h<sup>'-</sup> : BR result summary

Now, first results on 1 fb<sup>-1</sup> large data sample are available

→ High precision measurements:

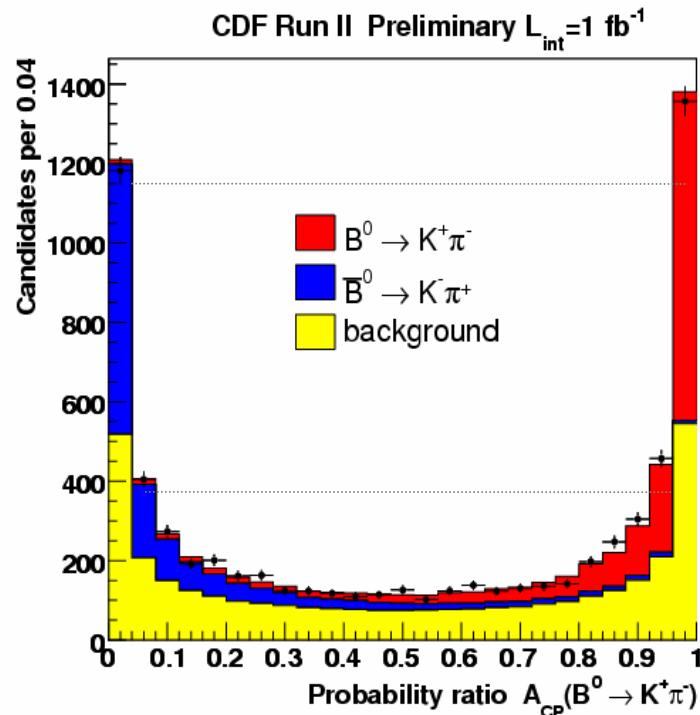
- a) first observation of rare modes such as  
 $B_s \rightarrow K^-\pi^+$ ,  $\Lambda_b \rightarrow p K^-$ ,  $\Lambda_b \rightarrow p \pi^-$
- b) New limits on  $B^0 \rightarrow K^+K^-$  and  $B_s \rightarrow \pi^+\pi^-$

CDF unique

Mode	New CDF (BR x 10 <sup>6</sup> ) (1 fb <sup>-1</sup> )
$B^0 \rightarrow \pi^+\pi^-$	$5.10 \pm 0.33(\text{stat.}) \pm 0.36(\text{syst.})$
$B^0 \rightarrow K^+K^-$	$0.39 \pm 0.16(\text{stat.}) \pm 0.12(\text{syst.})$
$B_s \rightarrow K^+K^-$	$24.4 \pm 1.4(\text{stat.}) \pm 4.6(\text{syst.})$
$B_s \rightarrow \pi^+K^-$	$5.0 \pm 0.75(\text{stat.}) \pm 1.0(\text{syst.})$
$B_s \rightarrow \pi^+\pi^-$	$0.53 \pm 0.31(\text{stat.}) \pm 0.40(\text{syst.})$

→ In this talk only highlights on  
Direct CPV  
in  $B^0 \rightarrow K^+\pi^-$  and  $B_s \rightarrow K^-\pi^+$

## Raw DCPV asymmetries

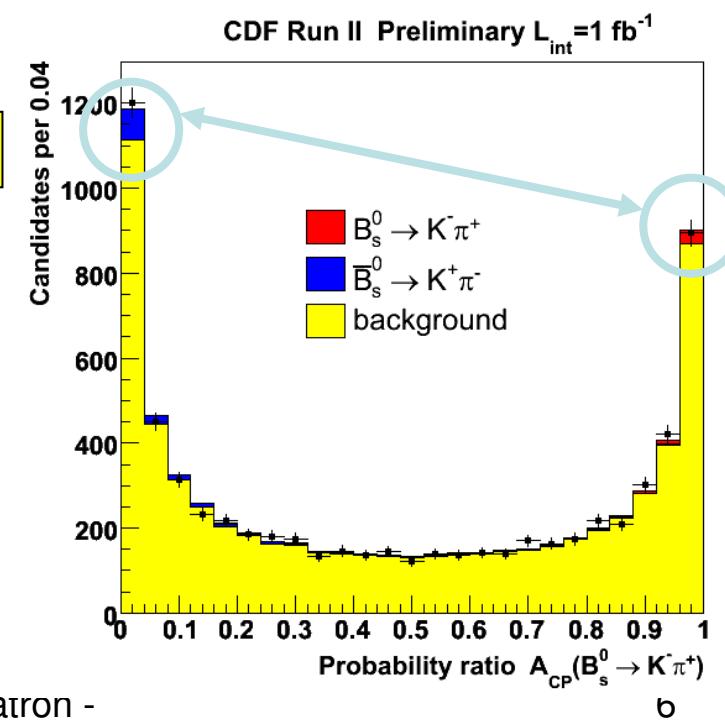


$B^0 \rightarrow K^+ \pi^-$

Plot of  $\text{pdf}(B^0)/[\text{pdf}(B^0)+\text{pdf}(\bar{B}^0)]$  shows the good separation achieved between  $B^0$  and  $\bar{B}^0$  ( $M_{\pi\pi}$ ,  $\alpha$ ,  $p_{\text{tot}}$ ,  $dE/dx$ )

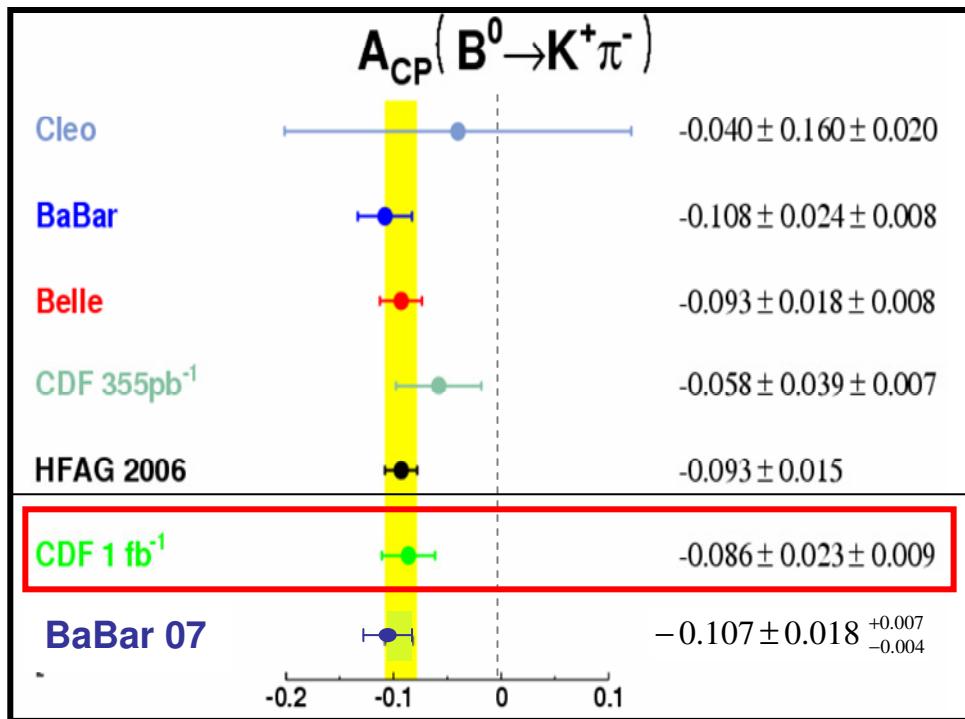
$B_s \rightarrow K^+ \pi^-$

- First measurement of direct CP asymmetry in the  $B_s$  system
- Very interesting to pursue with more data!
- Direct CP asymmetry measurements for  $\Lambda_b$  modes in progress.

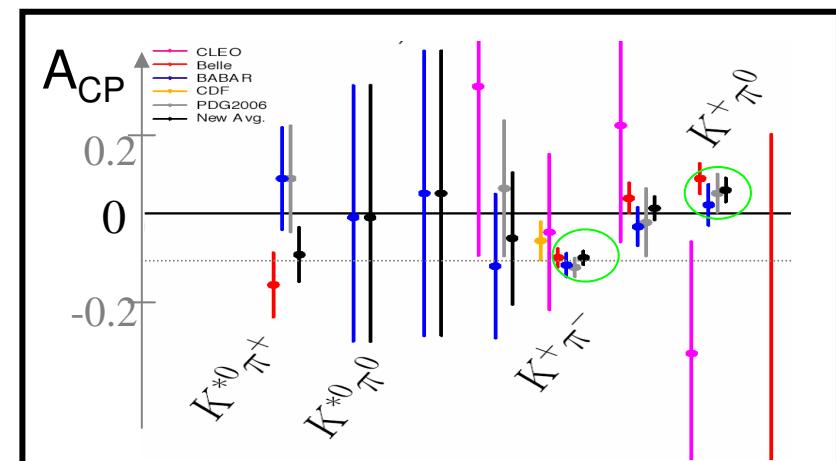


## New result on $A_{CP}(B^0 \rightarrow K^+ \pi^-)$ with $1 \text{ fb}^{-1}$

$$A_{CP} = \frac{N(\bar{B}^0 \rightarrow K^-\pi^+) - N(B^0 \rightarrow K^+\pi^-)}{N(\bar{B}^0 \rightarrow K^-\pi^+) + N(B^0 \rightarrow K^+\pi^-)} = -0.086 \pm 0.023 \text{ (stat.)} \pm 0.009 \text{ (syst.)}$$



- CDF competitive with BaBar/Belle
- Tevatron and B-Factories results agree
- 6-7  $\sigma$  effect
- Difference with  $A_{CP}(B^+ \rightarrow K^+ \pi^0)$  confirmed



New results for the  $B_s \rightarrow K^- \pi^+$  mode with  $1 \text{ fb}^{-1}$

$$BR(B_s^0 \rightarrow K^- \pi^+) = (5.0 \pm 0.75 \text{ (stat.)} \pm 1.0 \text{ (syst.)}) \times 10^{-6}$$

In agreement with latest prediction of SCET:  $(4.9 \pm 1.8) \cdot 10^{-6}$

Lower than previous predictions of QCDF and pQCD: [6-10]  $10^{-6}$

$$A_{\text{CP}} = \frac{N(\bar{B}_s^0 \rightarrow K^+ \pi^-) - N(B_s^0 \rightarrow K^- \pi^+)}{N(\bar{B}_s^0 \rightarrow K^+ \pi^-) + N(B_s^0 \rightarrow K^- \pi^+)} = 0.39 \pm 0.15 \text{ (stat.)} \pm 0.08 \text{ (syst.)}$$

## The Lipkin test: minimal assumptions, just SM

[Lipkin, Phys. Lett. B621:126, .2005],[Gronau Rosner Phys.Rev. D71 (2005) 074019].

Still marginal but sign and magnitude agree with SM predictions  
⇒ no evidence for exotic sources of CP violation (yet)

**Very interesting to pursue with more data !**



## Procedure

- Blind optimization using signal Monte Carlo sample and sideband data
- Normalize to the  $B^+ \rightarrow J/\psi K^+$  mode
- Reconstruct normalization mode in the same data sample, applying same criteria → reduce systematics, only ratio of efficiency matters
- Evaluate expected background, then “un-blind” the signal region and calculate BR or limit

**Similar discriminating observables for the two experiments:**

(Secondary vertex displacement, B pointing angle to the P.V., B isolation,.....)

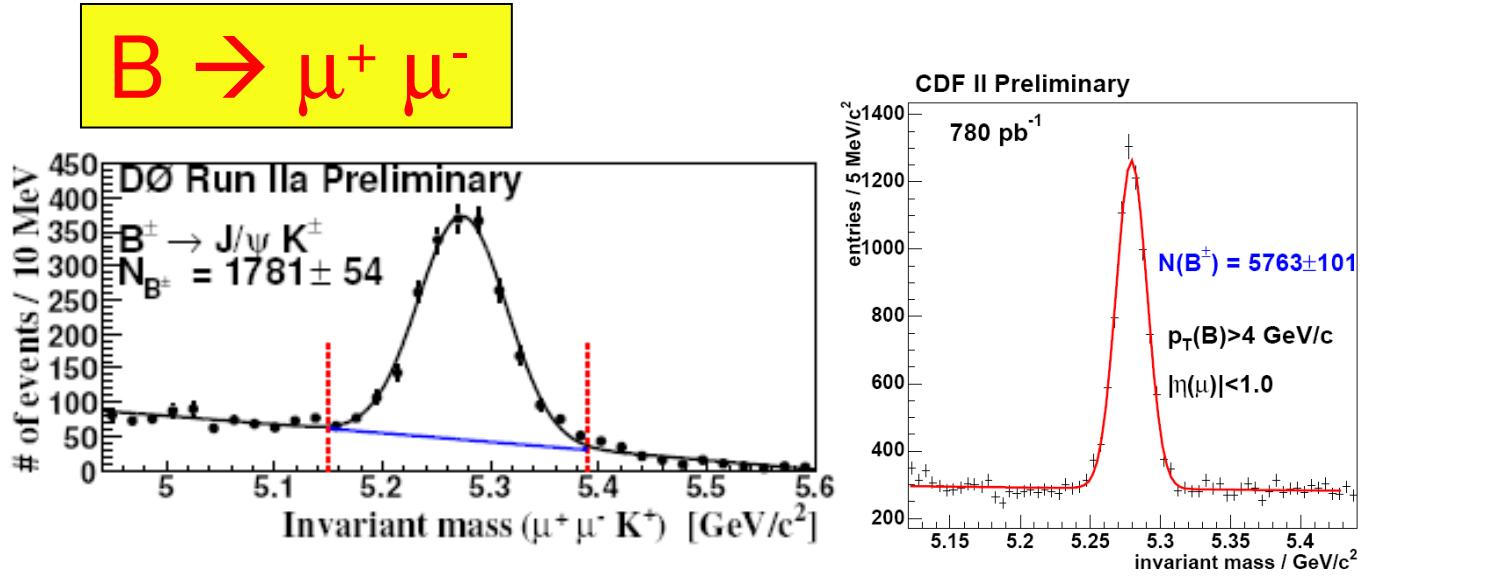
**Similar methods for the search optimization:**

- CDF: construct a likelihood ratio  $L_R$  with three discriminating observables and optimize  $L_R$  cut on the expected *a-priori* 90% C.L. limit
- D0: construct a likelihood ratio  $L_R$  with six discriminating observables and optimize  $L_R$  cut on

optimize  $L_R$  cut on

a):  $\epsilon_{\mu\mu} / \langle n_{up.lim.}(n_{exp.bkg.}) \rangle$ 
b):  $\epsilon_{\mu\mu} / (1 + \sqrt{B})$ 
]
→ same optimal values

**Normalization  
mode:  $B^+ \rightarrow J/\psi K^+$   
( $J/\psi \rightarrow \mu\mu$ )**



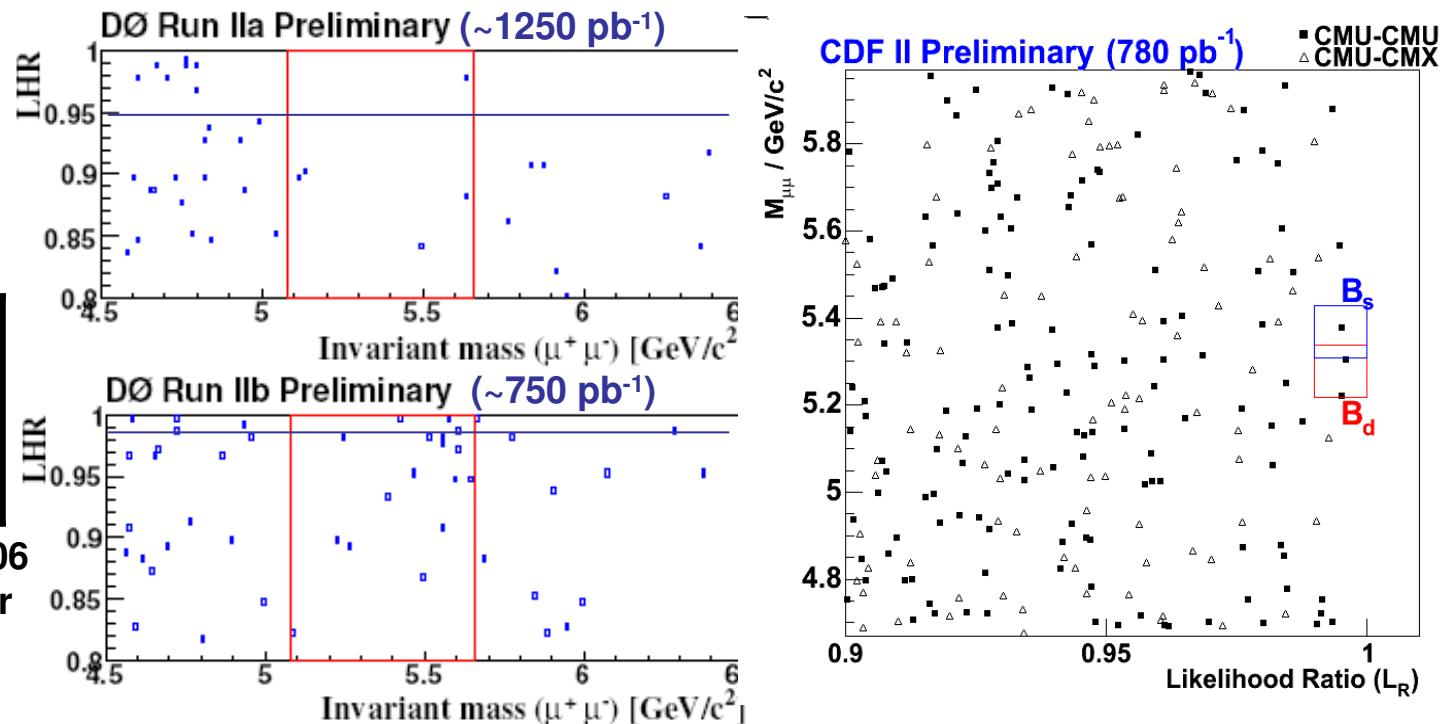
**Event yield  
after  
optimization**

**Optimal  $L_R$**

CDF	0.99
D0 Run IIa	0.946
D0 Run IIb	0.986

**Run IIb after Summer '06  
insertion of a new inner  
layer in the SMT**

F. Scuri



## B $\rightarrow$ $\mu\mu$ result summary

Experiment		B $^0_s$ search		B $^0_d$ search	
		Expected	Obs.	Expected	Obs.
CDF	780 pb $^{-1}$	1.27 $\pm$ 0.37	1	2.45 $\pm$ 0.40	2
D0	Run IIa (~1250 pb $^{-1}$ )	0.8 $\pm$ 0.2	1		
	Run IIb (~750 pb $^{-1}$ )	1.5 $\pm$ 0.5	2		

### Dominant uncertainty sources

	Rel.Unc. [%]
Background	~ 30
$f_u/f_s$	~ 13

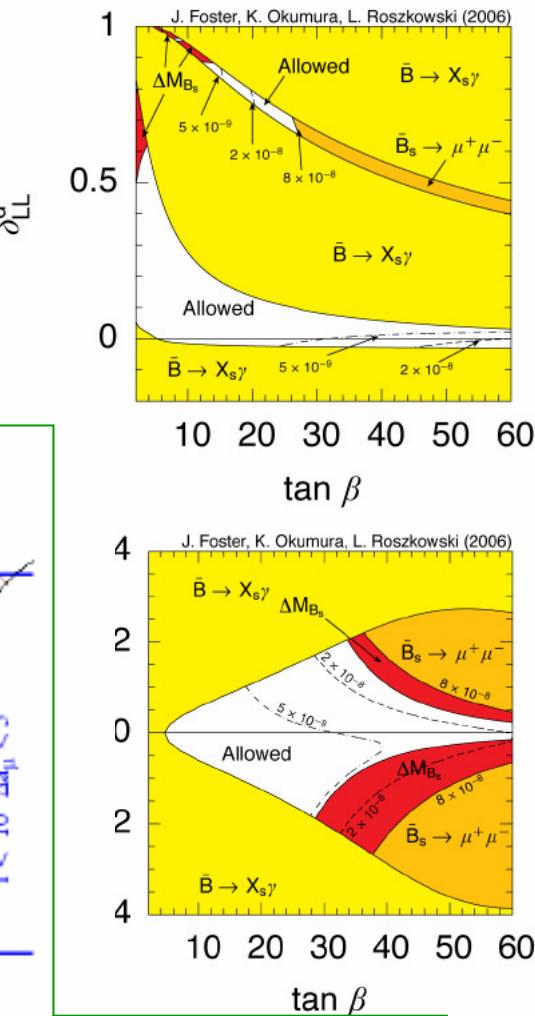
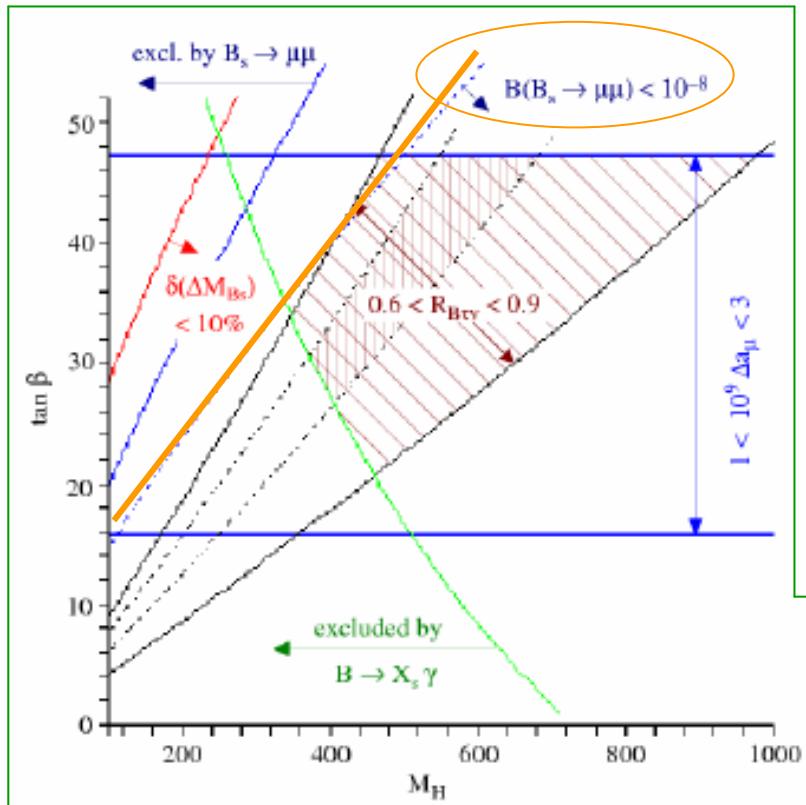
	$\mathcal{B}(B_s \rightarrow \mu^+ \mu^-)$ 90% (95%) C.L.	$\mathcal{B}(B_d \rightarrow \mu^+ \mu^-)$ 90% (95%) C.L.	Int.Lum. pb $^{-1}$
CDF	$< 8.0 \cdot 10^{-8} (10)$	$< 2.3 \cdot 10^{-8} (3)$	780
D0(combined)	$< 7.5 \cdot 10^{-8} (9.3)$	(*)	2000

(\*) D0 assumes the contribution of  $B_d \rightarrow \mu\mu$  to  $\mathcal{B}(B_s \rightarrow \mu\mu)$  suppressed due to  $|V_{td}/V_{ts}|^2 \sim 0.04$

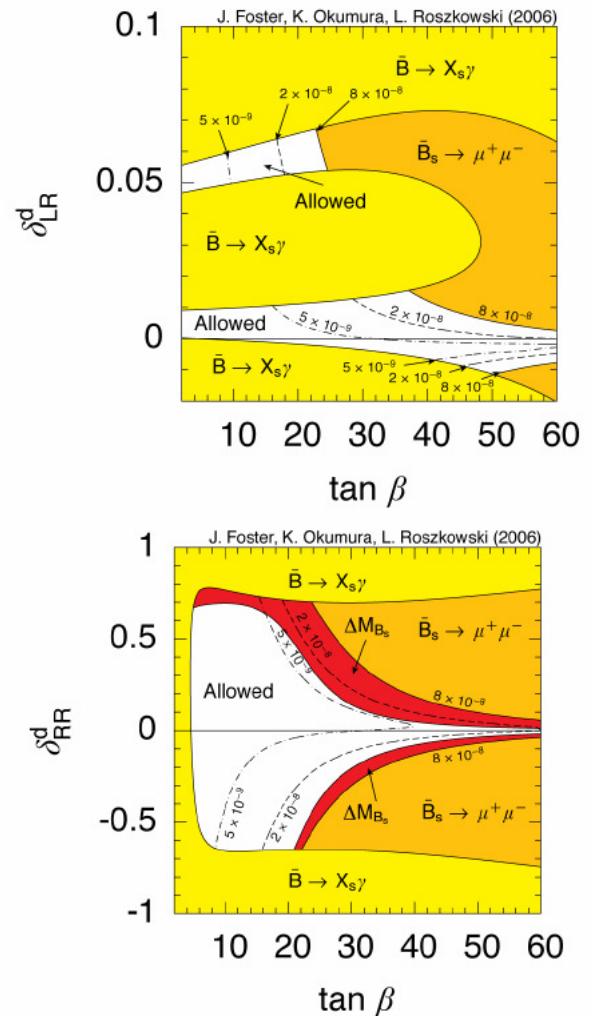
World best limit, compare  
 Babar (hep-ex/0408096, 110 fb $^{-1}$ )  
 $\text{BR}(B_d \rightarrow \mu\mu) < 8.3 \cdot 10^{-8}$  @ 90% C.L.

# Impact on New Physics

- Current constraints from  $\Delta m_s$  and  $B_s \rightarrow \mu\mu$  are differently effective in the new physics parameter phase space
- Improved limits on  $B_s \rightarrow \mu\mu$  can further constrain SUSY at large  $\tan\beta$



Constraints in MFV  
within MSSM  
(Hurth 07, Isidori 07)



Foster, Okumura, Roszkowski  
Phys.Lett. B641 (2006) 452

$$B^{(+)} \rightarrow \mu^+ \mu^- h^{(+)}$$

$$(b \rightarrow s \quad l^+ \; l^-)$$

**Studied decay modes:**

CDF:  $B^+ \rightarrow \mu^+ \mu^- K^+$ ,  $B^0 \rightarrow \mu^+ \mu^- K^{0*}$

CDF & D0:  $B_s \rightarrow \mu^+ \mu^- \Phi$

CDF/DØ similar analysis:

- Normalize signal to analogous  $B \rightarrow J/\psi h$  ( $J/\psi \rightarrow \mu\mu$ ) decays

$$\frac{BR(B \rightarrow \mu^+ \mu^- h)}{BR(B \rightarrow J/\psi h)} = \frac{N_{\mu\mu h}}{N_{J/\psi h}} \frac{\epsilon_{J/\psi h}^{total}}{\epsilon_{\mu\mu h}^{total}} BR(J/\psi \rightarrow \mu^+ \mu^-)$$

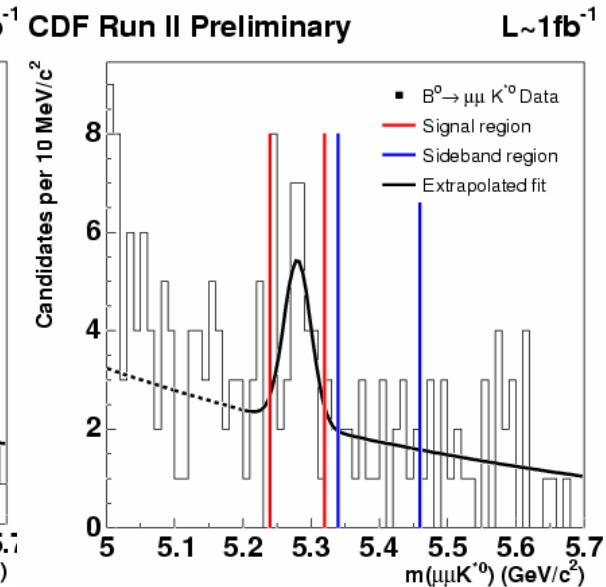
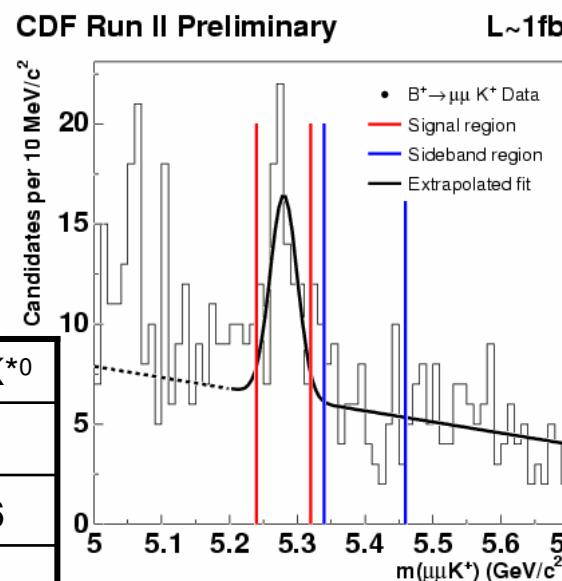
MC

- Exclude  $J/\psi$  and  $\psi'$  regions in the ( $\mu\mu$ ) inv. mass spectrum
- Blind optimization, sideband data used for optimization and bkg. estimate
  - CDF optimizes  $N_{sig} / \sqrt{N_{sig} + N_{bkg}}$
  - DØ optimizes  $N_{sig} / (1 + \sqrt{N_{bkg}})$

## B<sub>u,d</sub> yields (CDF)

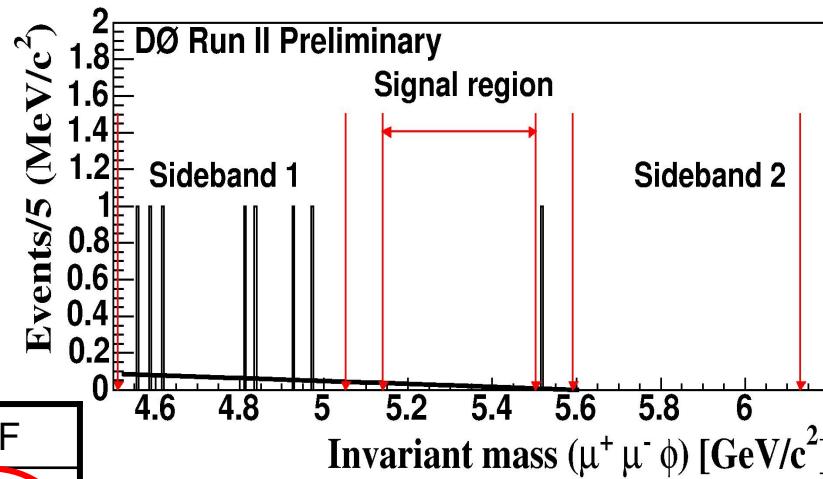
Fit shown only for illustration purpose

Mode	$B^+ \rightarrow \mu^+ \mu^- K^+$	$B^0 \rightarrow \mu^+ \mu^- K^{*0}$
$N_{\text{sig,win.}}$	90	35
$N_{\text{BG}}$	$45.3 \pm 5.8$	$16.5 \pm 3.6$
Significance	4.5	2.9



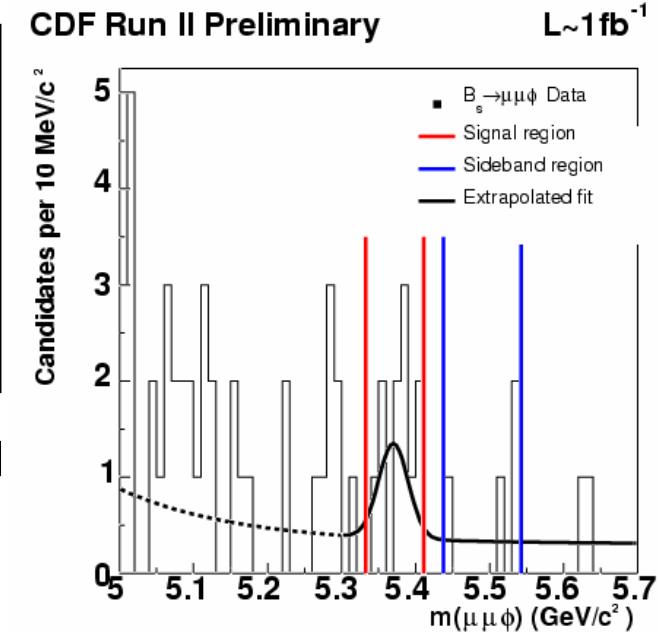
## B<sub>s</sub> yields

	D0	CDF
Obs.	0	11
Exp.	$1.6 \pm 0.6$	$3.5 \pm 1.5$
$\text{pb}^{-1}$	450	920

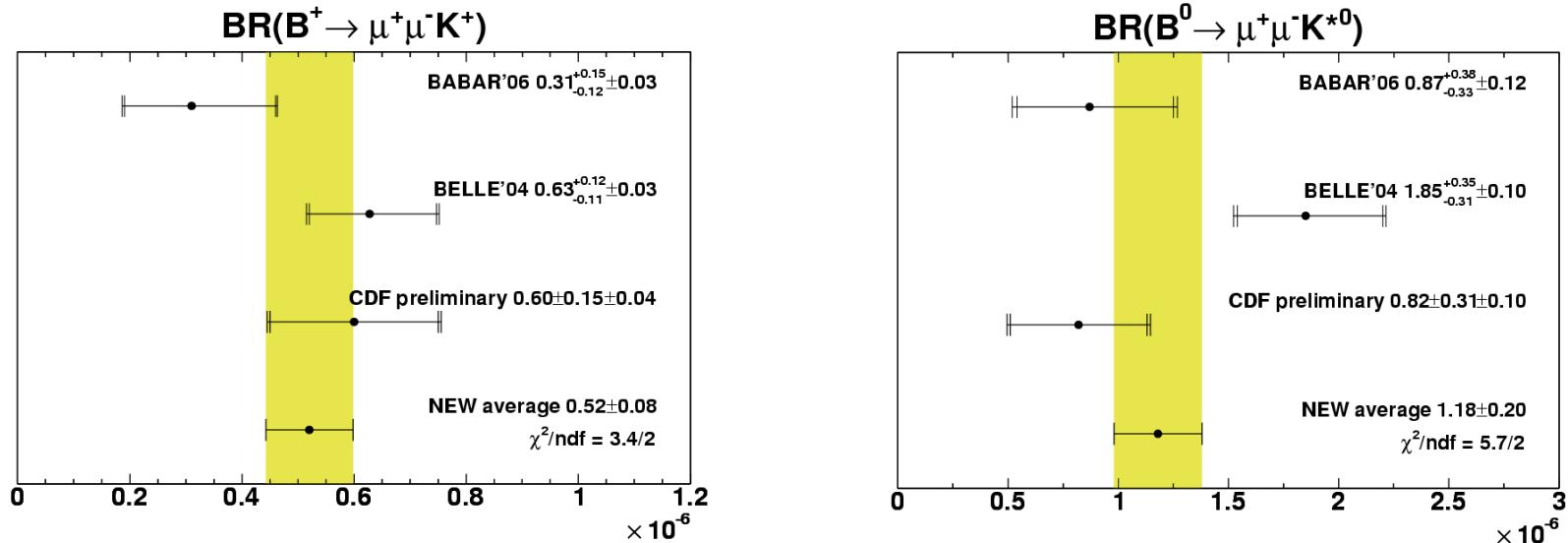


2.4  $\sigma$  significance

Rare B decays at the Tevatron - Moriond QCD 2007



## BR ( $B \rightarrow \mu\mu h$ ) result summary

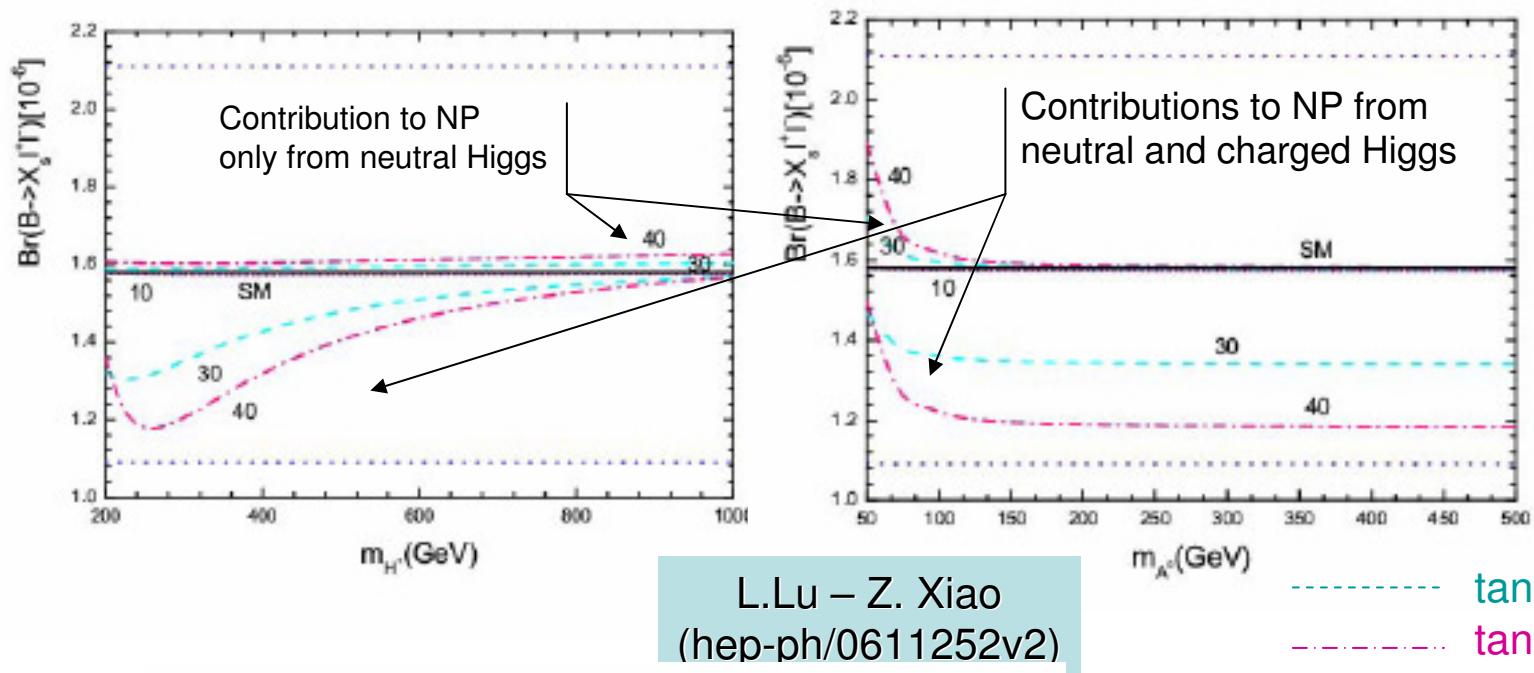


- Good agreement and similar uncertainty for B-Factories & Tevatron:
  - Babar PRD 73, 092001 (2006) ( $208 \text{ fb}^{-1} \rightarrow \sim 10 \mu\mu K^+, \sim 15 \mu\mu K^{*0}$ )
  - Belle hep-ex/0410006 ( $250 \text{ fb}^{-1} \rightarrow \sim 40 \mu\mu K^+, \sim 40 \mu\mu K^{*0}$ )

### Tevatron result summary

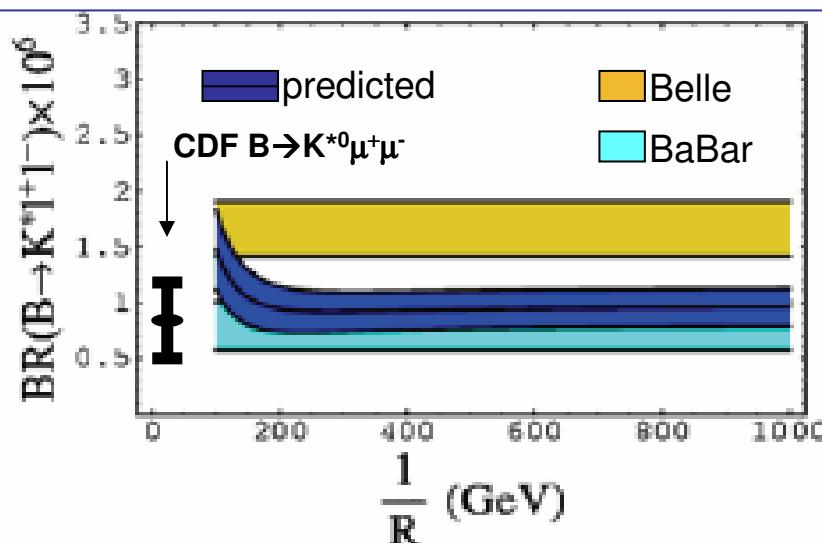
- $\text{BR}(B^+ \rightarrow \mu\mu K^+) = [0.60 \pm 0.15(\text{stat.}) \pm 0.04(\text{syst.})] \times 10^{-6}$  (45 ev. CDF)
- $\text{BR}(B^0 \rightarrow \mu\mu K^{*0}) = [0.82 \pm 0.31(\text{stat.}) \pm 0.10(\text{syst.})] \times 10^{-6}$  (20 ev. CDF)
- $\text{BR}(B_s \rightarrow \mu\mu\phi) < 2.4 \times 10^{-6} @ 90\% \text{ C.L.}$  (CDF,  $920 \text{ pb}^{-1}$ )
   
 $= [1.16 \pm 0.56(\text{stat.}) \pm 0.42(\text{syst.})] \times 10^{-6}$
- $\text{BR}(B_s \rightarrow \mu\mu\phi) < 3.3 \times 10^{-6} @ 90\% \text{ C.L.}$  (D0,  $450 \text{ pb}^{-1}$ )

# Impact on New Physics



**BR( $B \rightarrow X_s l^+ l^-$ )**  
**B-Factories average:**  
 $(1.60 \pm 0.51) \times 10^{-6}$

Tevatron can contribute to squeeze the error

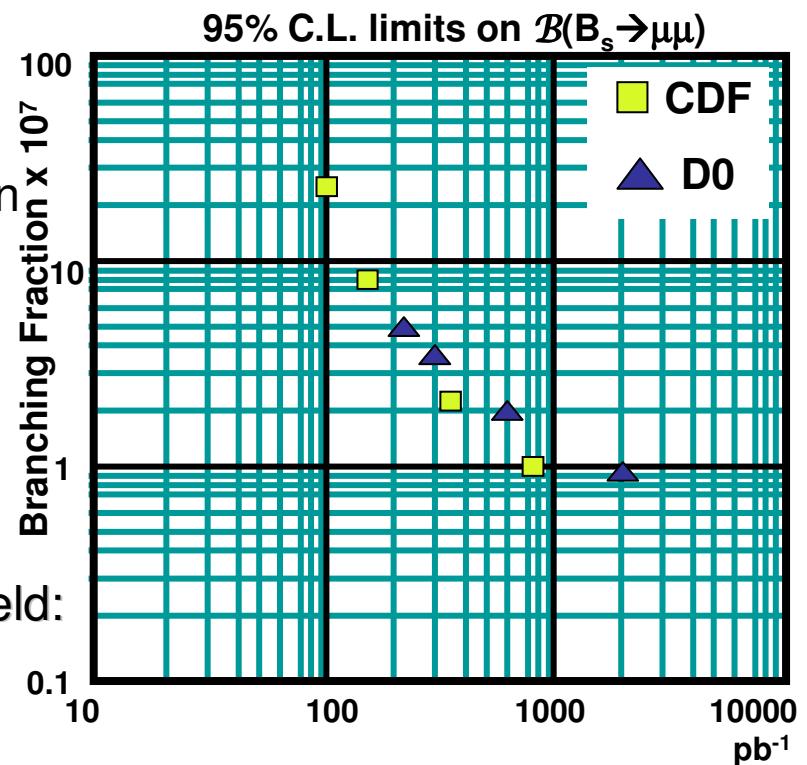


A special NP scenario:  
one universal extra dimension

F.De Fazio  
hep-ph/0610208

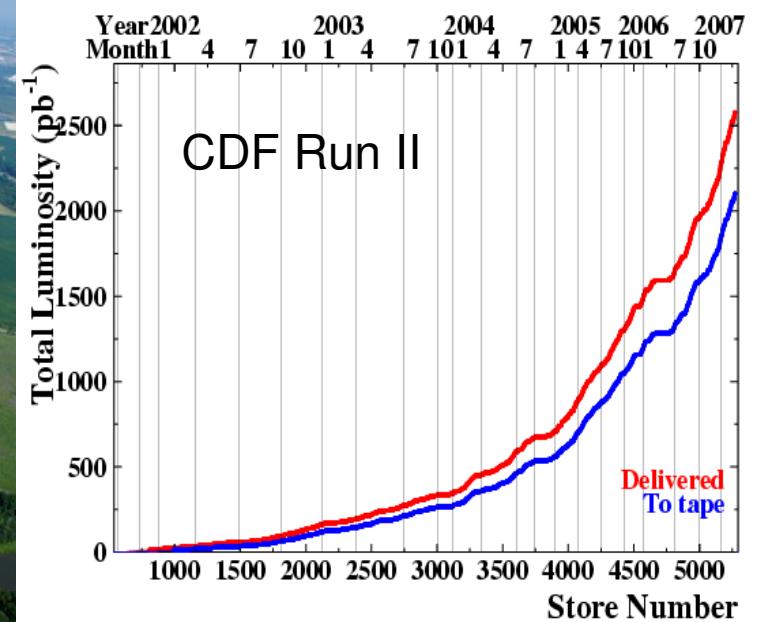
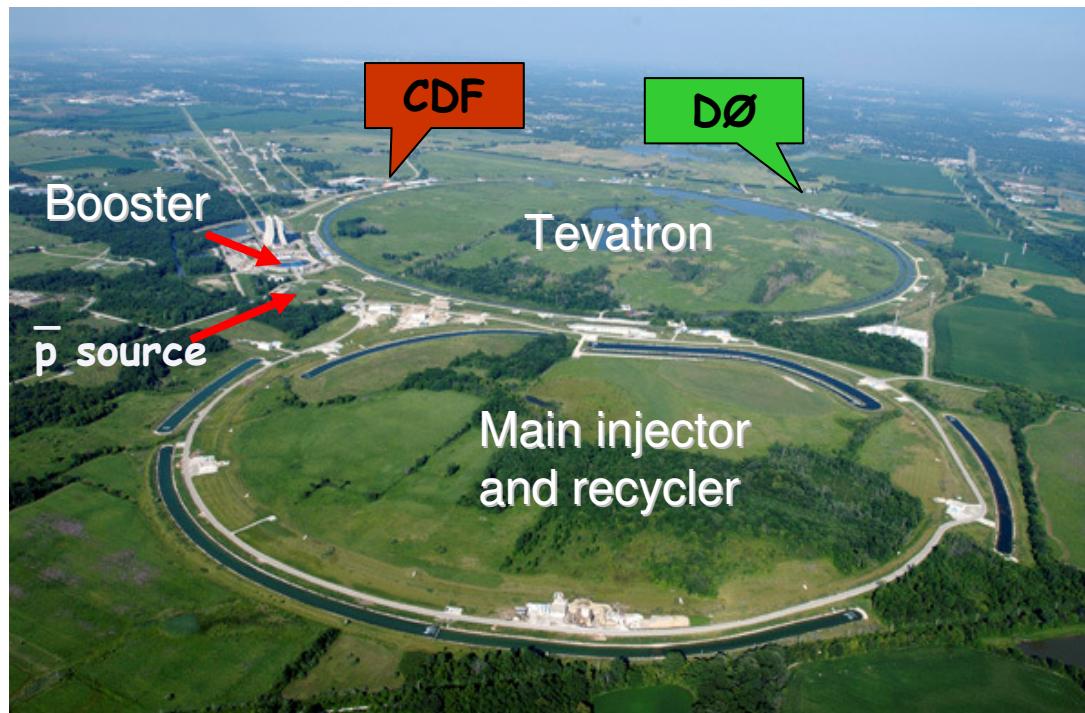
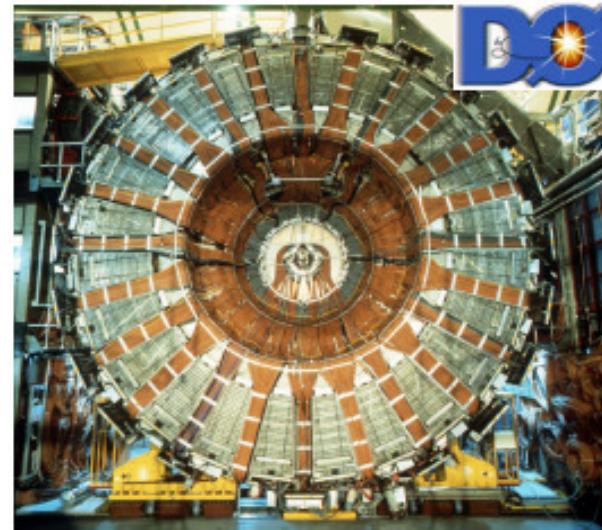
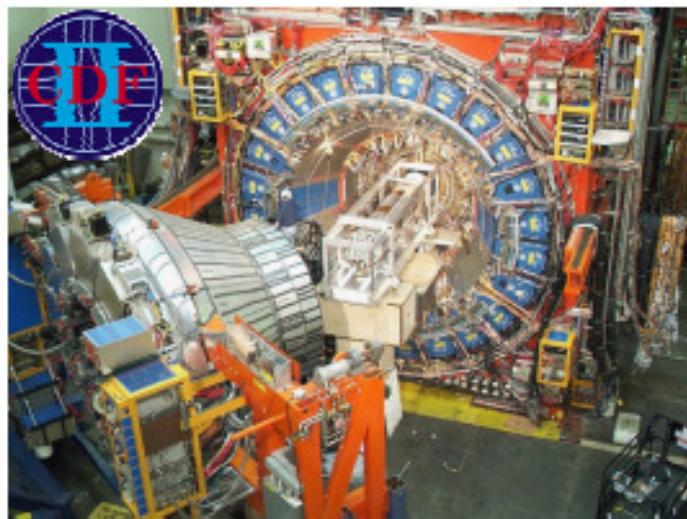
## Summary

- Tevatron is demonstrated to be a good place to study B rare decays offering:
  - different possibilities to constraint more and more New Physics,  $B \rightarrow \mu\mu$ ,  $b \rightarrow s l^+ l^-$
  - a physics program complementary to the B-Factories,  $B_s \rightarrow h^+ h^-$
- $B \rightarrow h^+ h^-$ :
  - First observation of  $B_s \rightarrow K^- \pi^+$
  - First observation of DCPV in  $B_s$ :  $A_{CP}(B_s \rightarrow K^- \pi^+)$  appears to be large in agreement with expectation
- $B \rightarrow \mu^+ \mu^-$ :
  - Limits scale almost linearly with luminosity
  - Current values entering the  $10^{-8}$  territory
  - First Tevatron result with  $2 \text{ fb}^{-1}$
  - Any signal at Tevatron will be evidence of NP
- $b \rightarrow s l^+ l^-$ :
  - CDF/DØ beginning exploration of the  $b \rightarrow s l^+ l^-$  field:
    - New solid  $B \rightarrow \mu\mu K$  signals from CDF; smaller errors on BR and  $A_{FB}$  will constrain/rule-out different NP scenarios
    - A  $2.4\sigma$  excess in the  $B_s \rightarrow \mu\mu\phi$  reported from CDF, upper limit close to SM prediction
- Now, over  $2 \text{ fb}^{-1}$  on tape: significantly improved results coming soon

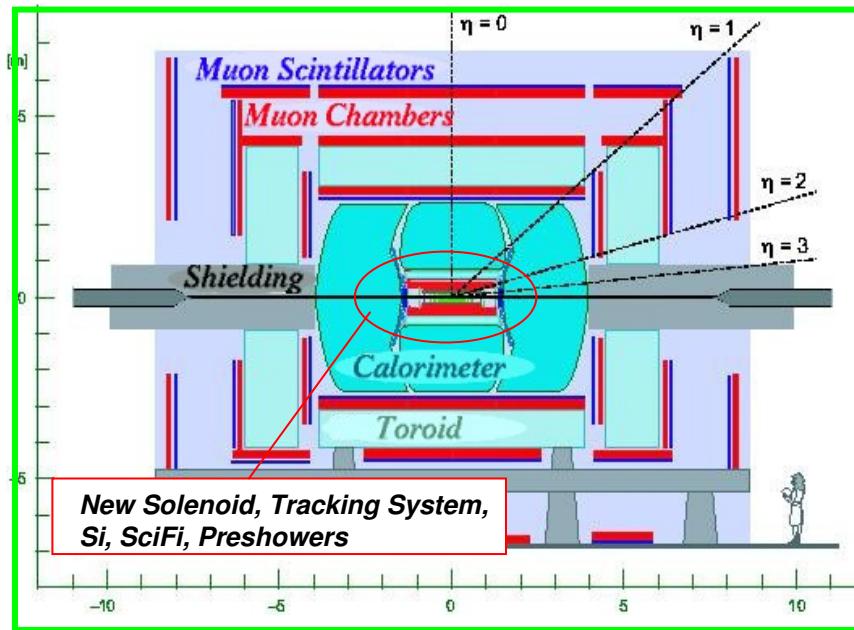


# Back-up slides

# The Tevatron at Fnal and the running experiments CDF and D~~O~~

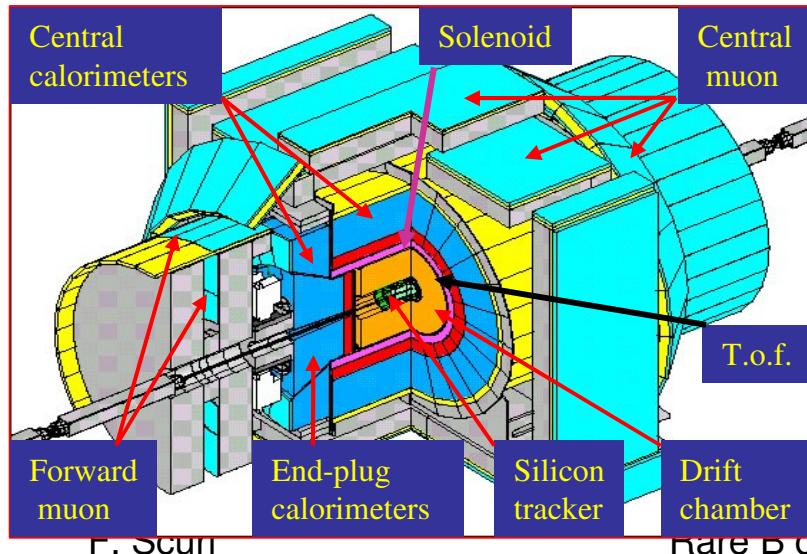


Two high performance detectors match the requirements...



### Both detectors:

- Silicon  $\mu$ -vertex
  - Central tracking in solenoid
  - Calorimeters and muon system
  - High rate trigger/DAQ
- 
- Good electron, muon ID and acceptance
  - Excellent tracking acceptance  $|\eta| < 2$  (3)



- L2 trigger on displaced vertices  $[\sigma(d_0) \sim 48 \mu\text{m}]$
- Excellent tracking resolution  $[\sigma(p_T)/p_T^2 \sim 0.15\% \text{ GeV}^{-1}]$
- Good low momentum PID



Rare B decays at the Tevatron -  
Moriond QCD 2007

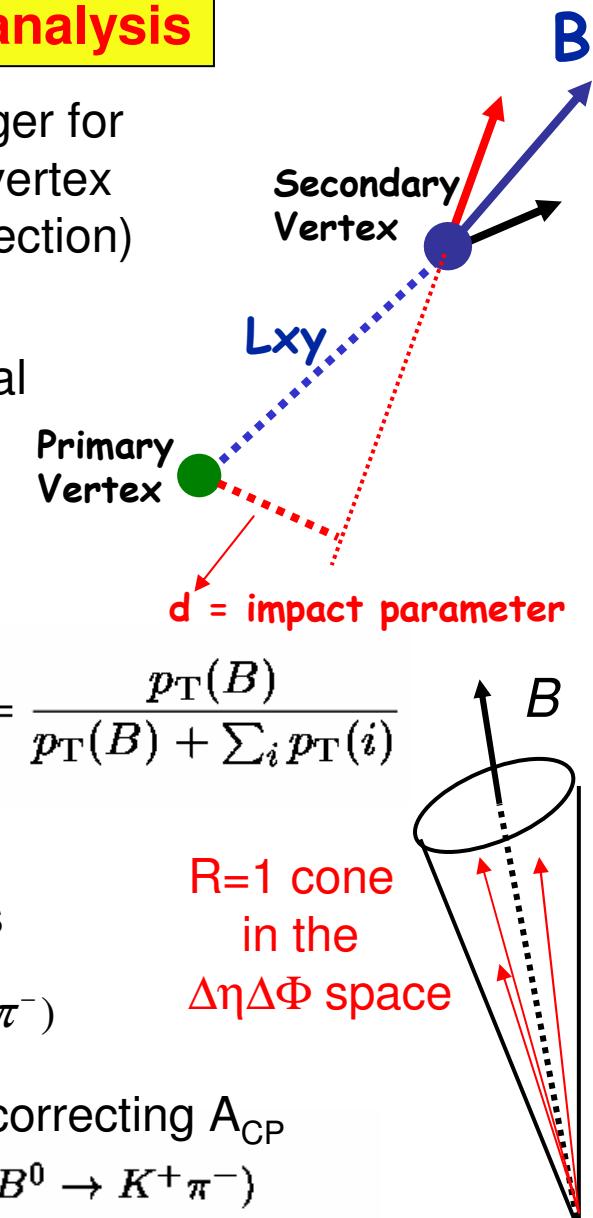
## Strategy for the $B \rightarrow h^+ h^-$ analysis

- Fully exploit the selection power of the CDF L2 SVT trigger for opposite charge track pairs originated from a displaced vertex (a 8500 events  $B_0(s) \rightarrow h^+ h^-$  signal just after trigger selection)
- Tighten trigger cuts in the offline optimization procedure by minimizing the expected uncertainty on each individual observable (raw asymmetry, event yield); analytical functions used to parameterize signal and background in the pseudo-experiments
- Add the isolation cut (efficiency measured in the  $B_s \rightarrow J/\Psi K^+$  control sample)
- Evaluate the sample composition with an unbinned Likelihood fit combining kinematics and PID
- Normalize to the most abundant  $B^0 \rightarrow K^+ \pi^-$  mode for BRs

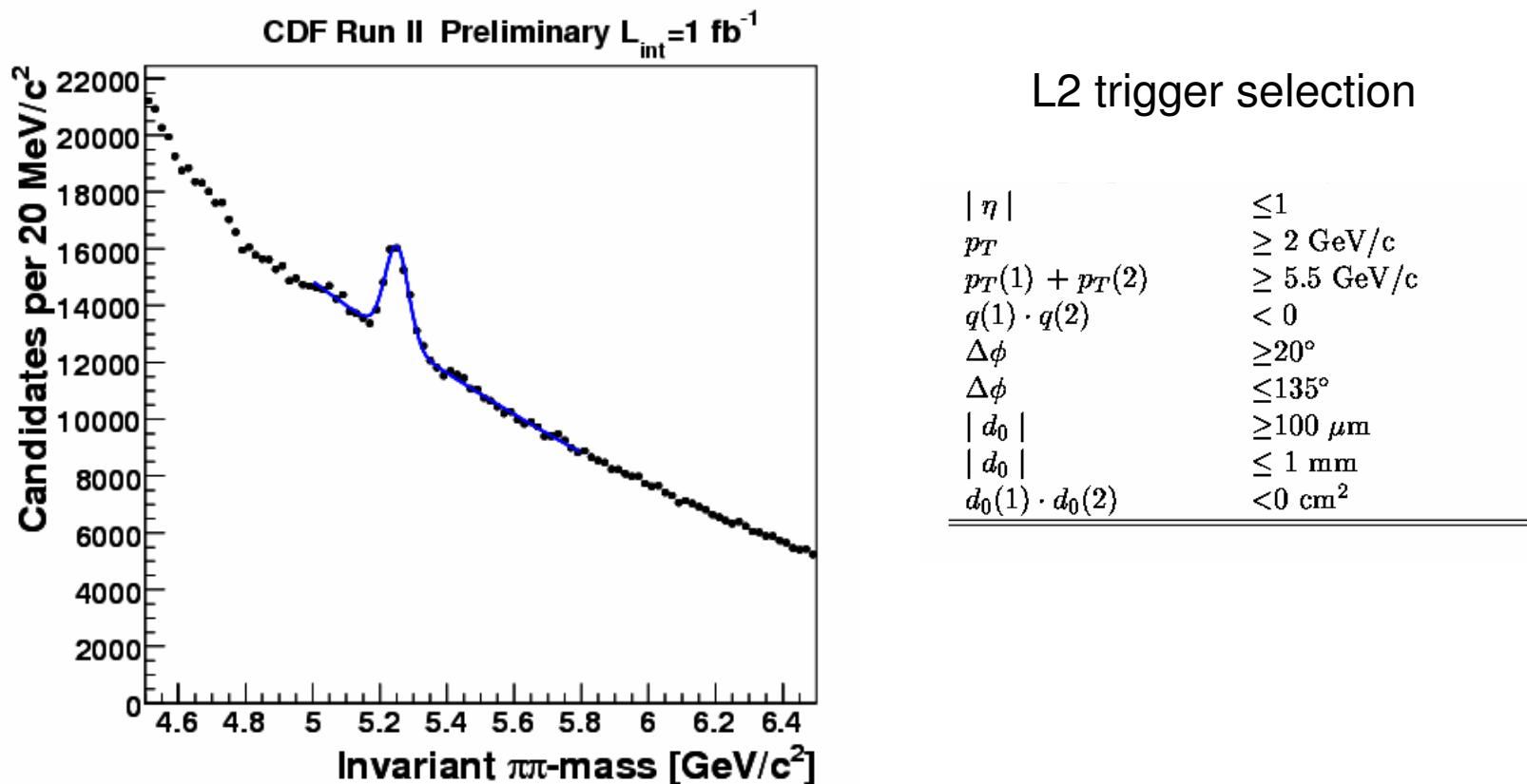
$$BR(B_s \rightarrow h^+ h^-) = \frac{N(B_s \rightarrow h^+ h^-)}{N(B^0 \rightarrow K^+ \pi^-)} \times \frac{f_b}{f_s} \times \frac{\epsilon_{B^0 \rightarrow K^+ \pi^-}^{tot}}{\epsilon_{Bs \rightarrow h^+ h^-}^{tot}} \times BR(B^0 \rightarrow K^+ \pi^-)$$

- Only different  $K^+/K^-$  interactions with material matter for correcting  $A_{CP}$

$$A_{CP}(B^0 \rightarrow K^+ \pi^-) = \frac{N_{\text{raw}}(\bar{B}^0 \rightarrow K^- \pi^+) \cdot \boxed{\frac{\epsilon(K^+ \pi^-)}{\epsilon(K^- \pi^+)}} - N_{\text{raw}}(B^0 \rightarrow K^+ \pi^-)}{N_{\text{raw}}(\bar{B}^0 \rightarrow K^- \pi^+) \cdot \boxed{\frac{\epsilon(K^+ \pi^-)}{\epsilon(K^- \pi^+)}} + N_{\text{raw}}(B^0 \rightarrow K^+ \pi^-)}$$



## $\pi\pi$ invariant mass: offline confirmation of the trigger selection



## Separating decays modes

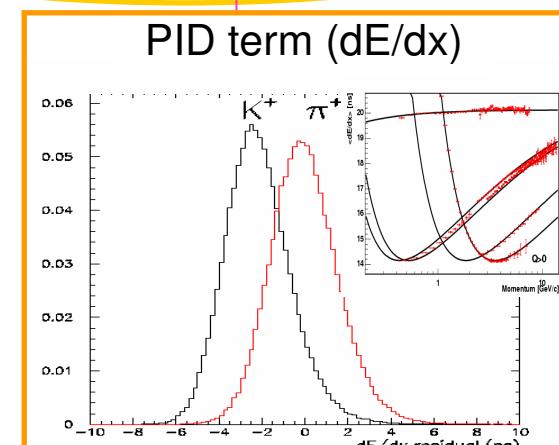
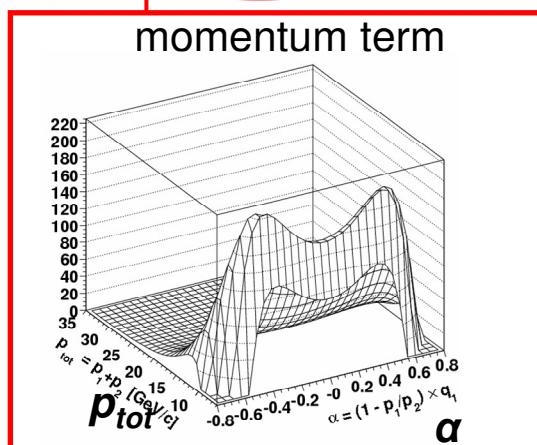
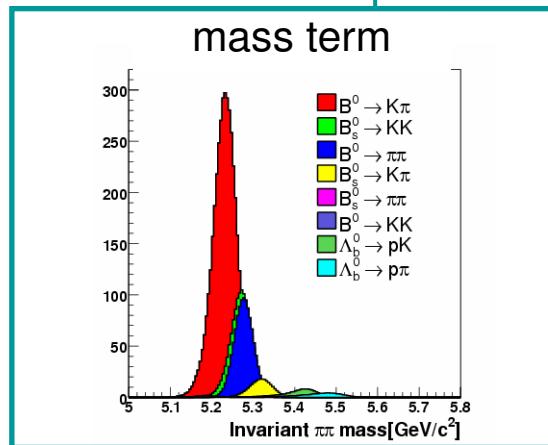
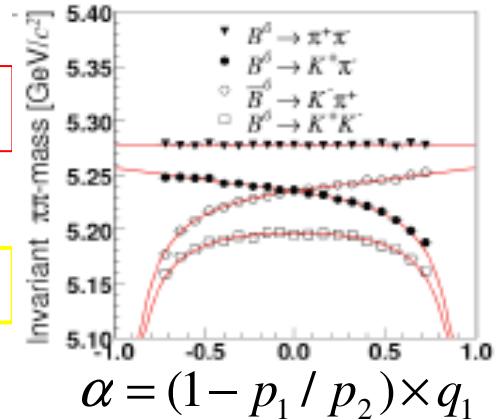
Un-binned ML fit using 5 observables ( $M_{\pi\pi}, p_{tot}, \alpha, ID_1, ID_2$ )

$$\mathcal{L}(\vec{\theta}) = \prod_{i=1}^N \mathcal{L}_i(\vec{\theta})$$

fraction of  $j^{th}$  mode, to be determined by the fit

$$\mathcal{L}_i(\vec{\theta}) = (1 - b) \sum f_j \mathcal{L}_j^{\text{sign}} + b \mathcal{L}^{\text{bckg}}$$

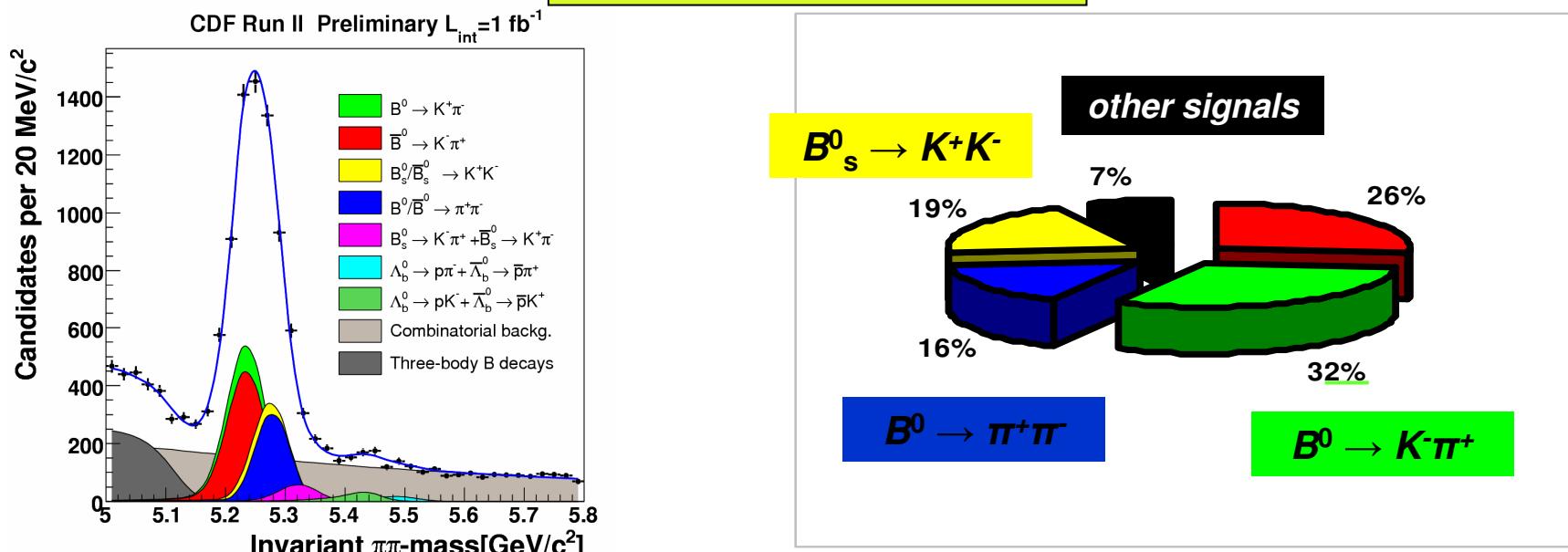
$$pdf_j^{\text{m}}(m_{\pi\pi} | \alpha, p_{tot}; \vec{\theta}) \cdot pdf_j^{\text{p}}(\alpha, p_{tot}; \vec{\theta}) \cdot pdf_j^{\text{PID}}(ID_1, ID_2 | p_{tot}, \alpha; \vec{\theta})$$



Signal shapes: from MC and analytic formula  
Background shapes: from data sidebands

sign and bckg shapes  
from  $D^0 \rightarrow K^-\pi^+$

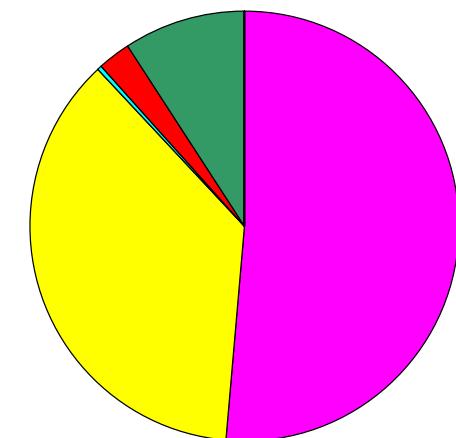
## Signal composition



## Systematics $A_{\text{CP}}(B^0 \rightarrow K^+\pi^-)$

- dE/dx model ( $\pm 0.0064$ );
- nominal  $B$ -meson masses input to the fit ( $\pm 0.005$ );
- global mass scale ( $\approx 0$ );
- momentum background model ( $\pm 0.001$ );
- $M_{\pi\pi}$  background model ( $\pm 0.003$ ).

## Contributions to Systematics

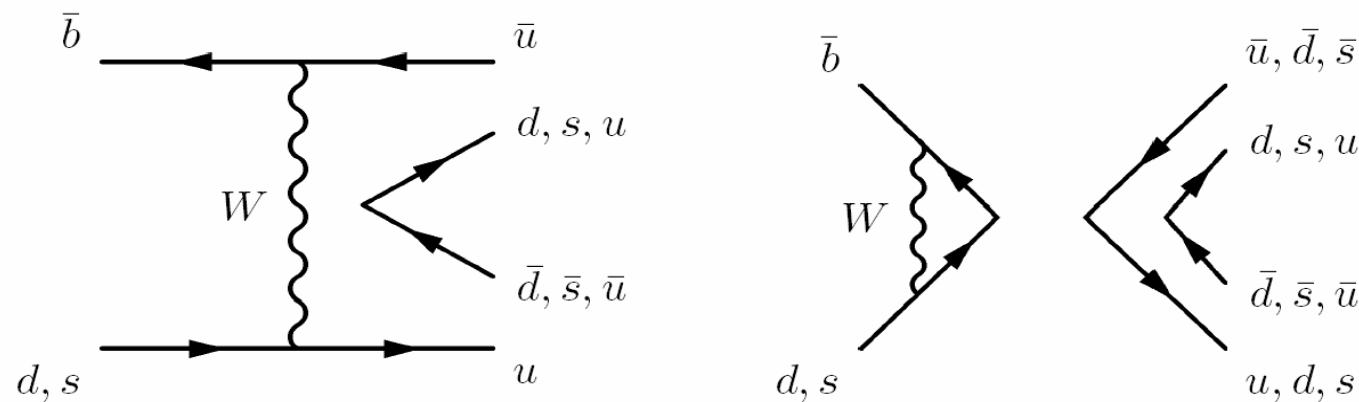


F. Scuri

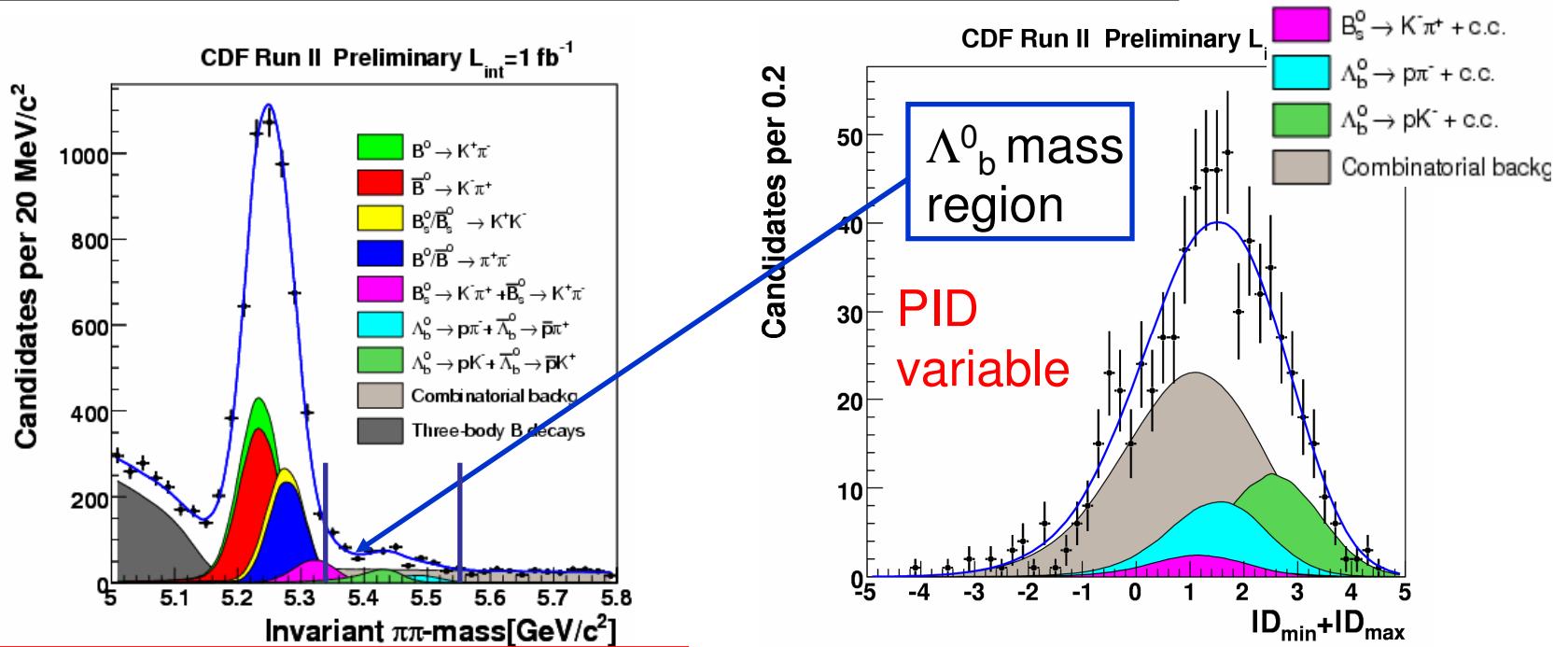
Rare B decays at the Tevatron -  
Moriond QCD 2007

## Pure annihilation modes

- BRs small and difficult to predict
- $B_s \rightarrow \pi\pi$  (exp. x3 larger than  $B^0 \rightarrow K\bar{K}$ )



# First observation: $\Lambda_b^0 \rightarrow p\pi^-$ and $\Lambda_b^0 \rightarrow pK^-$



$$N_{\text{raw}}(\Lambda_b^0 \rightarrow pK^-) = 156 \pm 20 \text{ (stat.)} \pm 11 \text{ (syst.)}$$

11  $\sigma$

$$N_{\text{raw}}(\Lambda_b^0 \rightarrow p\pi^-) = 110 \pm 18 \text{ (stat.)} \pm 16 \text{ (syst.)}$$

6  $\sigma$

$$\frac{BR(\Lambda_b^0 \rightarrow p\pi^-)}{BR(\Lambda_b^0 \rightarrow pK^-)} = 0.66 \pm 0.14 \text{ (stat.)} \pm 0.08 \text{ (syst.)}$$

$\Lambda_b^0 \rightarrow p\pi^-$  entangled to  
 $B_s^0 \rightarrow K^+\pi^-$

Large DCPV expected  
for both modes

Ratio of BR in agreement with predictions (0.60-0.62)

[Mohanta et al. Phys.Rev. D63 (2001) 074001]

## $B \rightarrow h^+ h^-$ : prospects for RunII

- Until the beginning of the planned Y(5S) run at Belle and the beginning of LHCb (at least fall 2008 ) only CDF has **simultaneous access to  $B_s^0$ ,  $B_d^0$  (plus B-baryons)**
- $A_{CP}(B^0 \rightarrow K\pi)$  at  $\approx 1\%$  and  $A_{CP}(B_s^0 \rightarrow K\pi)$  at  $\approx 5\%$
- High precision measurements for all BRs
  - Opportunity to observe annihilation modes  $B^0 \rightarrow KK$ ,  $B_s^0 \rightarrow \pi\pi$
  - Measurements of BR/ $A_{CP}$   $\Lambda_b^0 \rightarrow pK/p\pi$
- Time-dependent  $A_{CP}(t)$  for  $B^0 \rightarrow \pi\pi$ ,  $B_s^0 \rightarrow KK$ , all ingredients are ready  $\Delta m_s, \epsilon D^2 \approx 4\%$

## Discriminating observables: (almost) the same in the two experiments

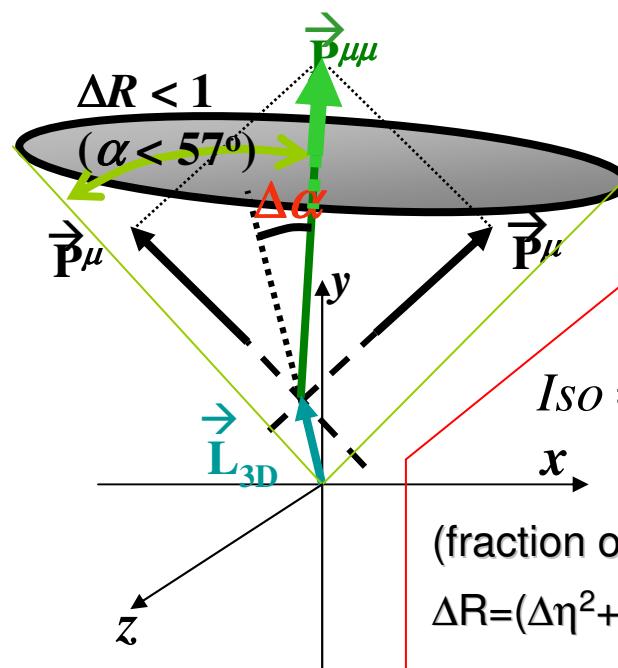
1) B vertex displacement:

$$\text{CDF} \rightarrow \lambda = \frac{c L_{3D} M}{|\vec{p}(B)|}$$

$$\text{D}\bar{\text{o}} \rightarrow L_{xy} / \sigma_{L_{xy}}$$

2) “pointing angle ( $\Delta\alpha$ )”:

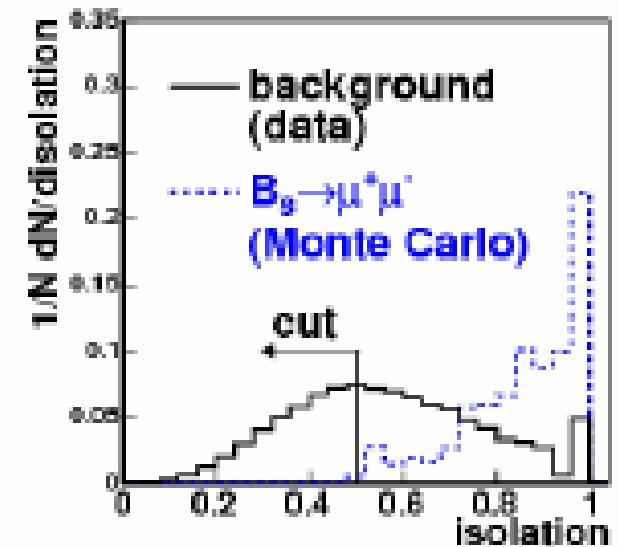
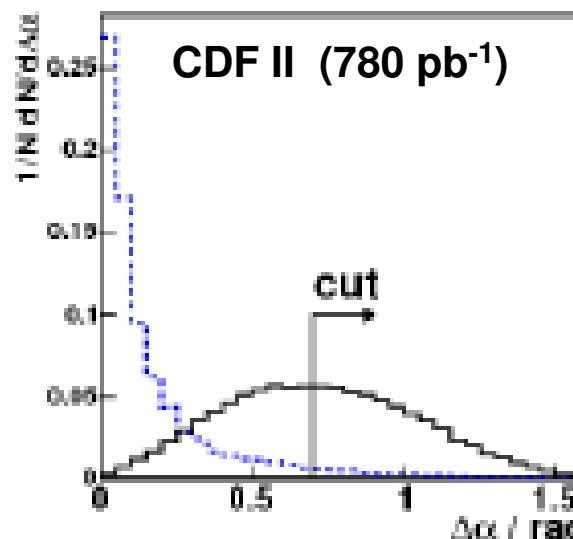
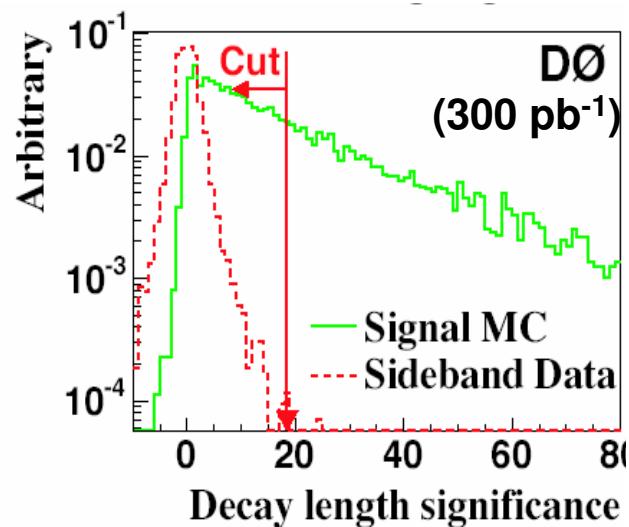
$$\Delta\alpha = \angle(\vec{p}(B) - \vec{L}_{3D})$$



3) Isolation (Iso):

$$Iso = \frac{p_T(B)}{p_T(B) + \sum_i p_T^i (\Delta R_i < 1)}$$

(fraction of tracks with  $p_T$  within the  $\Delta R = (\Delta\eta^2 + \Delta\phi^2)^{1/2} = 1$  cone of the B cand.)



## Search optimization: similar methods

### CDF

- Define two search regions in the ( $\mu\mu$ ) inv. mass spectrum around the nominal  $B_d$  and  $B_s$  masses, 120 MeV/c<sup>2</sup> wide ( $\pm 2.5 \sigma_M$  measured in the  $B \rightarrow hh$  analysis)

- Background PDF from data sidebands
- construct a likelihood ratio  $L_R$  using 3D proper dec. len.  $\lambda$ ,  $\Delta\alpha$ , Iso

$$L_R = \frac{\prod_i P_s(x_i)}{\prod_i P_s(x_i) + \prod_i P_b(x_i)}$$

- Optimize  $L_R$  cut on the expected *a-priori* 90% C.L. limit; 0.99 is the optimal value
- Evaluate the fake  $B \rightarrow hh$  rate

### D0

- Define a single signal region around the  $B_s$  nominal mass, 180 MeV/c<sup>2</sup> wide
- B from linear extrapolation of the sidebands
- Construct a likelihood ratio LR on six discriminating observables
  - Pointing angle
  - 2D decay length significance
  - Isolation
  - B impact parameter
  - minimal muon impact param.
  - $\chi^2$  vertex probability

- Optimize  $L_R$  on:

a):  $\varepsilon_{\mu\mu} / \langle n_{\text{up.lim.}}(n_{\text{exp.bkg.}}) \rangle$

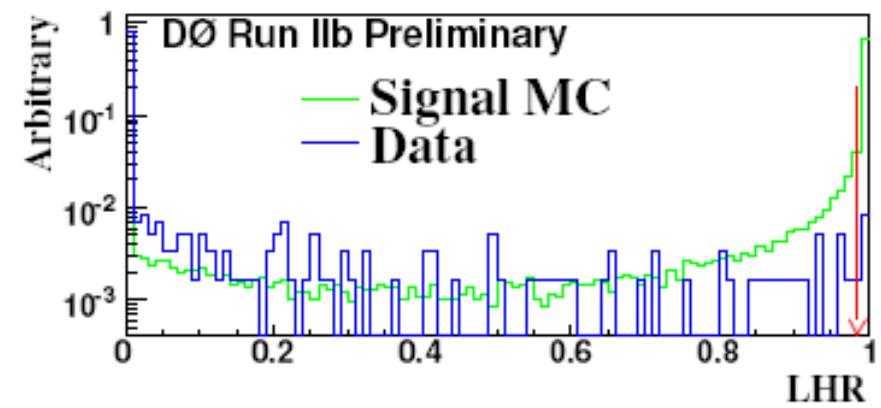
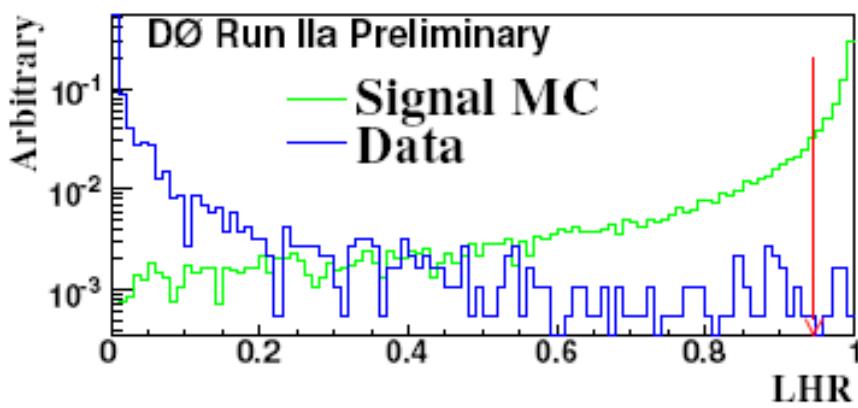
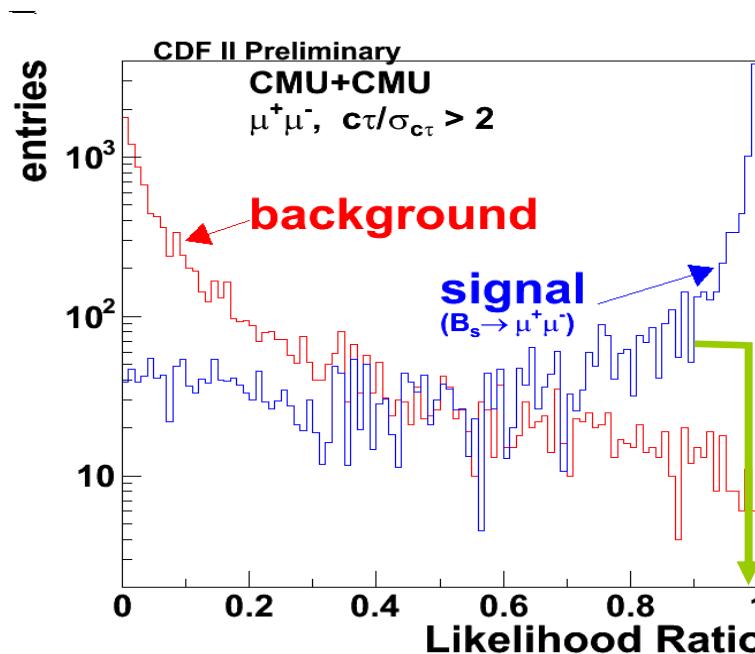
b):  $\varepsilon_{\mu\mu} / (1 + \sqrt{B})$

→ same optimal values

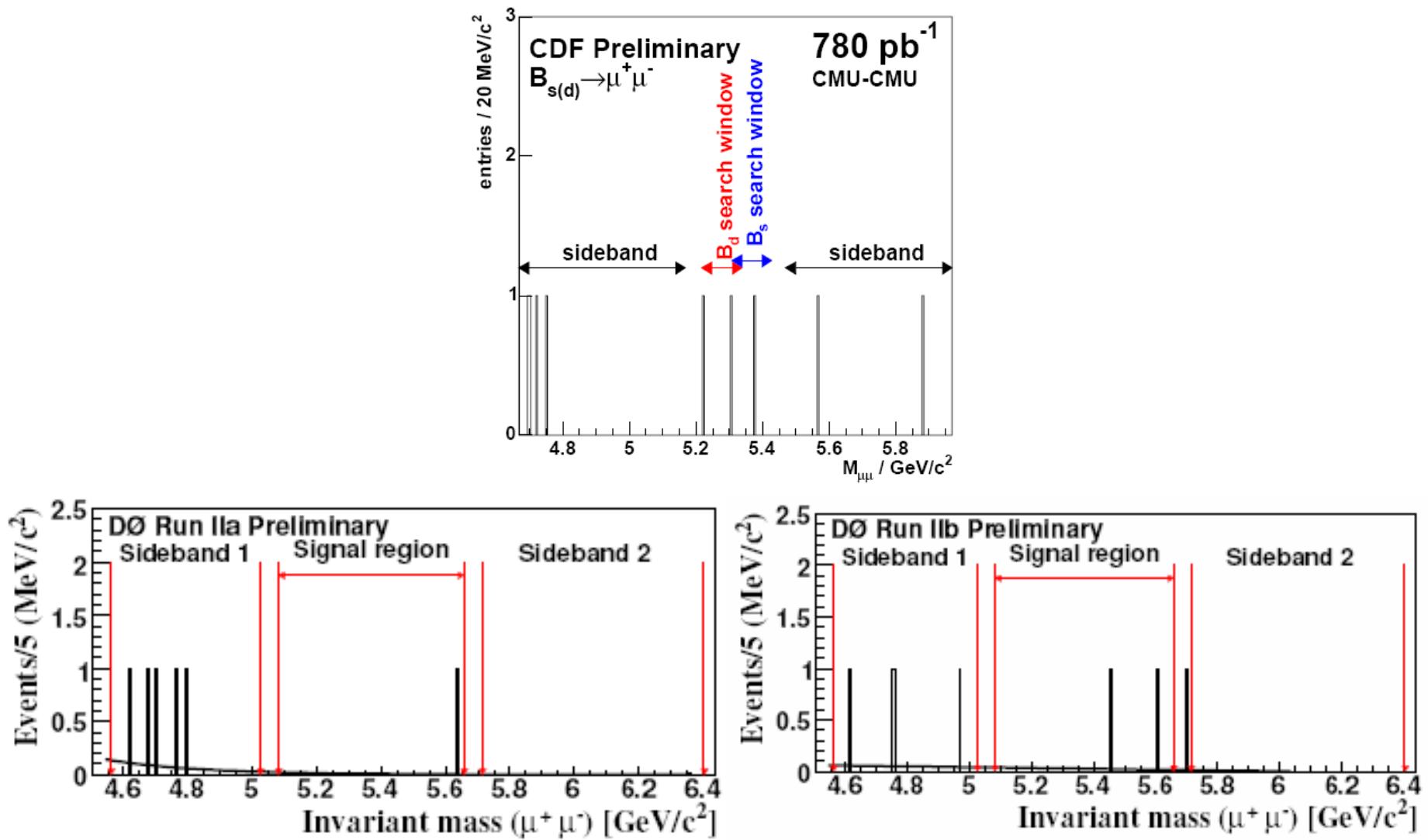
**Extraction of the upper limit  $N_{B \rightarrow \mu^+ \mu^-}^{90\%(95\%)}$**

Bayesian approach assuming flat prior for  $\mathcal{B}(B \rightarrow \mu\mu)$  and Gaussian uncertainties

## Likelihood Ratio



## B $\rightarrow$ $\mu\mu$ event yield after optimization



## B → μμ : area of improvement

- Improved muon selection based on additional information:
  - Energy deposition in the calorimeter
  - $dE/dx$  in the drift chamber
- significant reduction in fakes expected.
- Neural Net based final discriminant with additional background suppression power
- use the 2-dimensional dimuon mass-discriminant plane to evaluate signal/limit

## B<sub>s</sub> → μμ h (b→s l<sup>+</sup>l<sup>-</sup>) status

- B<sub>d</sub> and B<sup>+</sup> modes established at B-factories:

$$BR(B^+ \rightarrow \mu\mu K^+) = 0.34^{+0.19}_{-0.14} \times 10^{-6} \text{ (PDG 06)}$$

$$BR(B_d \rightarrow \mu\mu K^{*0}) = 1.22^{+0.38}_{-0.32} \times 10^{-6} \text{ (PDG 06)}$$

- Tevatron goals: re-establish B-factories observations and look for the unseen B<sub>s</sub> → μμφ mode; predicted BR(B<sub>s</sub> → μμφ) = 1.6 × 10<sup>-6</sup> C. Geng and C. Liu, J. Phys. G 29, 1103 (2003)

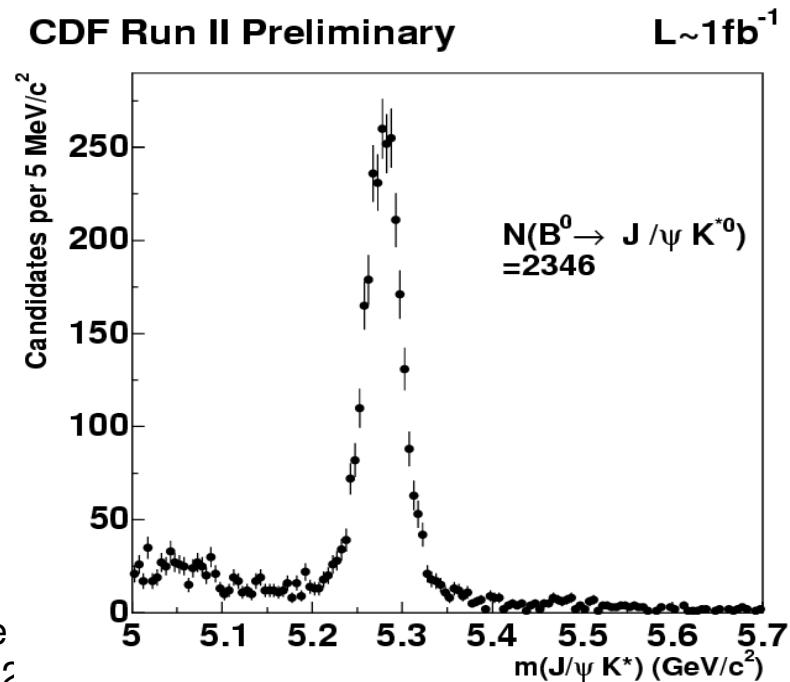
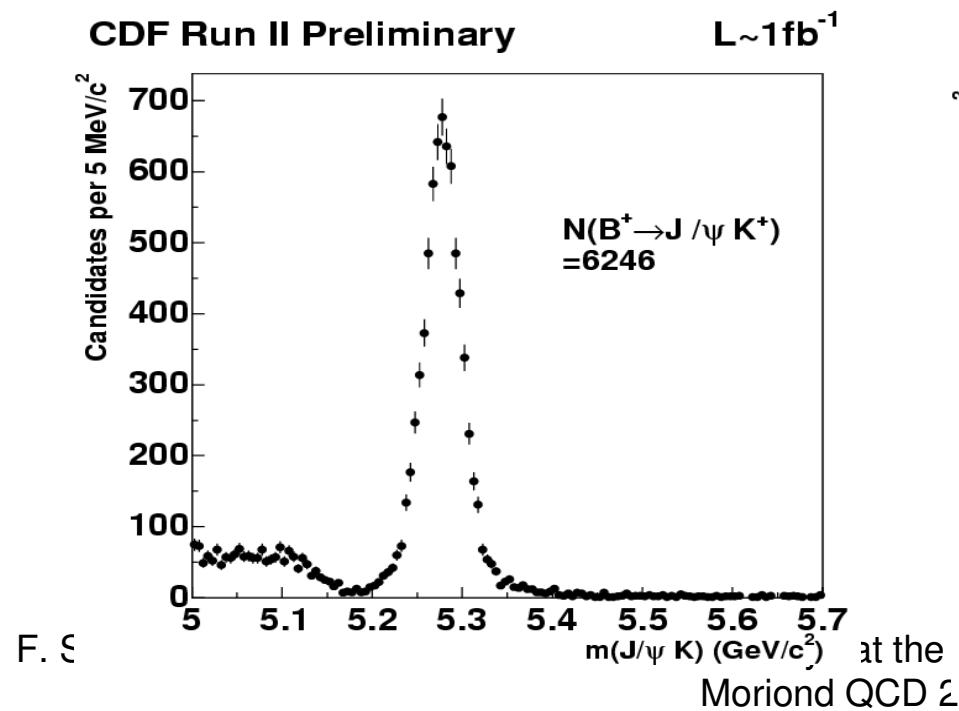
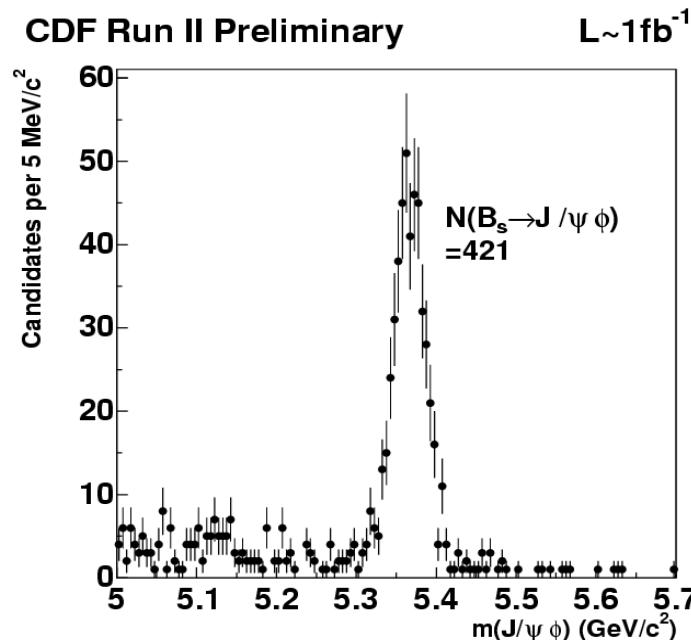
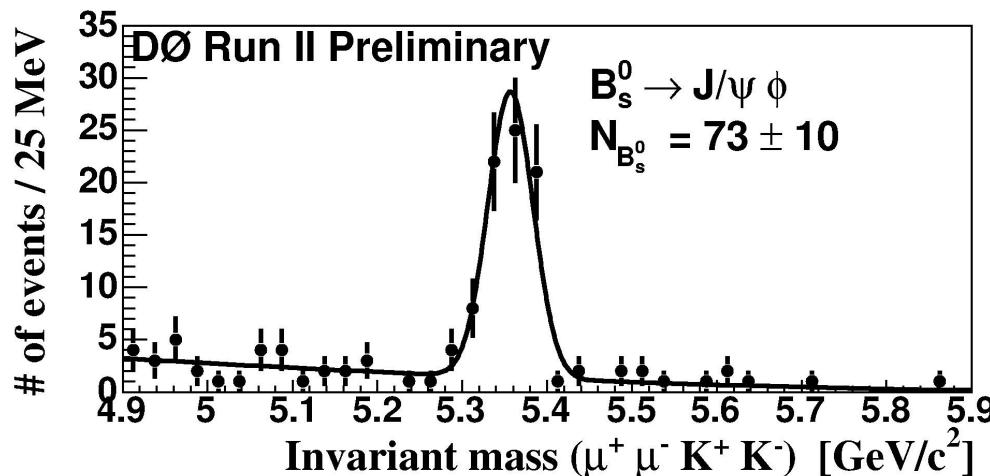
## Strategy

- Normalize signal to analogous B → J/ψh (J/ψ → μμ) decays

$$\frac{BR(B \rightarrow \mu^+ \mu^- h)}{BR(B \rightarrow J/\psi h)} = \frac{N_{\mu\mu h}}{N_{J/\psi h}} \frac{\epsilon_{J/\psi h}^{total}}{\epsilon_{\mu\mu h}^{total}} BR(J/\psi \rightarrow \mu^+ \mu^-)$$

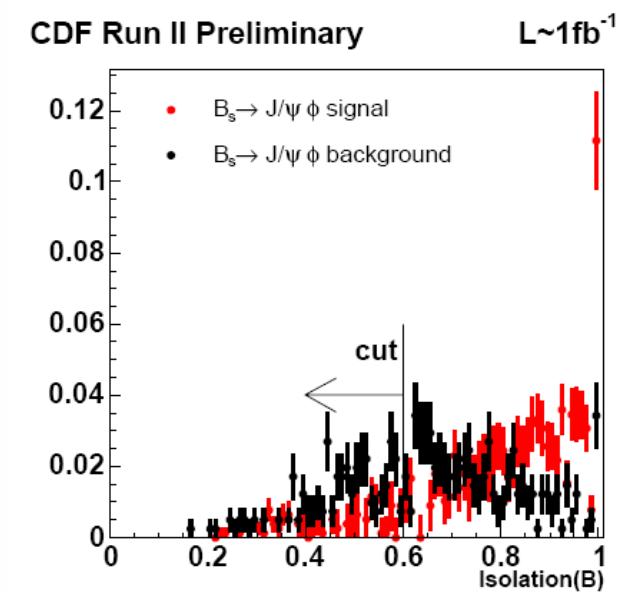
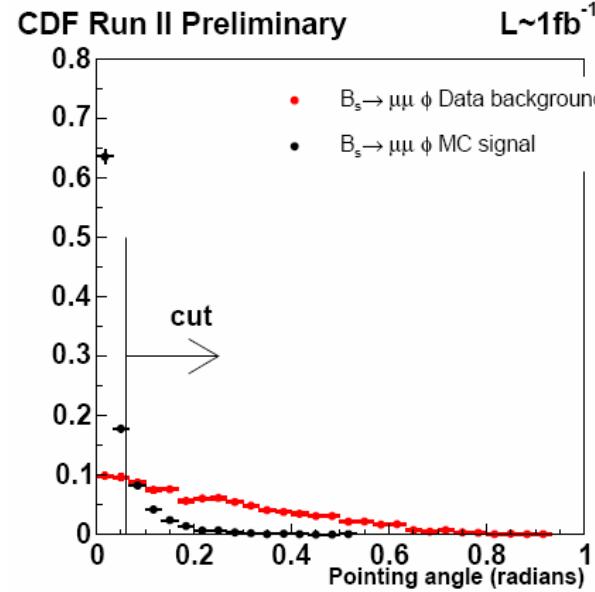
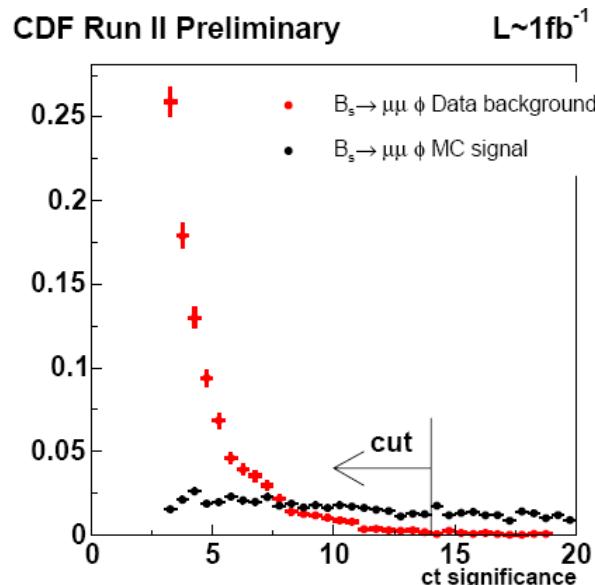
- Exclude J/ψ and ψ' regions in the (μμ) inv. mass spectrum
- Blind optimization, sideband data used for optimization and background estimate
- Monte Carlo for efficiency ratios with normalization mode  
(To estimate signal efficiency for the B<sup>+</sup>, B<sub>d</sub> modes, CDF uses data yields of B<sub>d</sub>, B<sup>+</sup> in the normalization modes, scaled using the w.a. of measured BR(B<sub>(d)</sub><sup>+</sup> → μμ K<sup>(\*)</sup>) )

**$B^{(\pm)} \rightarrow \mu^+ \mu^- h^{(\pm)}$  Normalization modes**



# Signal Selection Optimization

Discriminating observables (after pre-selection cuts):



$$L_{XY} / \sigma(L_{XY})$$

$$|\varphi_B - \varphi_{vtx}|$$

$$Iso = \frac{p_T(B)}{p_T(B) + \sum_i p_T^i(\Delta R_i < 1.0)}$$